Natural Gas RD&D
FY 2013-2014 Program

Stakeholder Input to Planning Process

CALIFORNIA ENERGY COMMISSION

1516 NINTH STREET

November 28, 2012

To: Researchers and Other Interested Parties:

Since 2008, the California Energy Commission (Energy Commission) has developed annual budget plans for natural gas research, development and demonstration (RD&D) activities. Currently, the Energy Commission is developing the budget plan for fiscal year 2013-14 and estimates that a total of $24 million will be available for natural gas RD&D. As part of this process, we seek ideas for natural gas research initiatives in the following areas: energy efficiency, renewable energy, natural gas infrastructure, natural gas related environmental research, and natural gas related transportation research.

If you have research ideas, please complete the attached initiative template. This template asks you to discuss the issues/barriers your research will overcome, as well as provide a description of the initiative, stakeholders, background and justification. The information contained in your template should be no more than two pages. Complete one template per initiative.

In 2004, California Public Utilities Commission (CPUC) designated the Energy Commission as the administrator for the natural gas research program. In the last several years, the CPUC allocated an annual funding level of $24 million and defined public interest natural gas research as those that "are directed towards developing science or technology, and 1) the benefits of which accrue to California citizens and 2) are not adequately addressed by competitive or regulated entities." The decision also directs that natural gas RD&D projects meet the following criteria:

- Focus on energy efficiency, renewable technologies, conservation, and environmental issues.
- Support state energy policy.
- Offer a reasonable probability of providing benefits to the general public.
- Consider opportunities for collaboration and co funding opportunities with other entities.

Please email your suggested initiatives by **December 14, 2012**, to Jessie Rosales at jesselyn.rosales@energy.ca.gov . A public workshop will be scheduled to discuss proposed natural gas research concepts.

Thank you,

Laurie ten Hope

Deputy Director

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Natural Gas – Proposed Research Initiative

Program Area:

Building End Use Energy Efficiency.

Reduce on site natural gas use and address technology gaps hindering the achievement of improved efficiency and reduced natural gas use in commercial and residential buildings: a) advance efficient technologies, design tools, and operations; b) demonstrate affordable, comfortable, energy efficient buildings; c) maintain or increase productivity while reducing energy consumption and emissions. Examples include: improvement to water heating and distribution efficiency; improvements to food service cooking equipment, advanced HVAC and envelopes; solar water heating; indoor air quality; and other innovative and advanced natural gas saving systems that also reduce air emissions.

Name of Initiative:

1. **Heat Pump Assisted Solar Thermal Collectors**

Issues or Barriers

Natural gas is an attractive energy source due to its relative low cost compared to alternatives and availability. Natural gas is much more attractive as a fuel source compared to, for example, coal or fuel oil due to its cost and reduced greenhouse gas (GHG) emissions. However, natural gas is still a fossil fuel product that generates GHGs and is most certainly not as environmentally friendly as renewable energy sources such as solar photovoltaic (PV) or solar thermal. In addition, when energy efficiency retrofits employing increased air sealing are performed, combustion safety becomes a significant issue where natural gas appliances are employed. In such "tight" homes combustion appliances can become starved of combustion air resulting in carbon monoxide poisoning and/or fire.

Initiative Description and Purpose

This study/demonstration would investigate the unique economic and environmental benefits of systematically combining solar thermal collectors and water source heat pumps for residential water heating and space heating and cooling. The expectations to be demonstrated and tested are reductions in GHGs, reduction in combustion risk and more cost competitiveness compared with natural gas in residential applications. Preliminary calculations indicate a significant increase in efficiency when combining unglazed solar thermal collectors with high coefficient of performance (COP) heat pumps in a synergistic application in which not only domestic water is heated but space heating and cooling is also provided. Little is currently known about how much more effective solar assisted water and hydronic space heating can be when integrated with water to water heat pumps. This study/demonstration would design, implement, and measure results.

Hydronic space cooling would also be investigated. Unglazed thermal solar collectors can be utilized in reverse during night time to radiate heat energy to the night sky. This cooling would be augmented by the water to water heat pumps accessing either the domestic water supply, geothermal loop or large storage tank depending on temperature sensed by a smart controller.

Solar thermal systems have two important advantages that become significant when taking a holistic systems approach to home energy.

First, solar thermal systems have tanks where valuable thermal energy can be stored. These tanks coupled with smart controls enable systems to be integrated with the utility smart grid system to dampen or eliminate peak loads and improve heating & cooling efficiencies.

Second, water to water heat pumps enable significant reductions in the amount of electrical energy needed for water and space heating. Typical solar thermal water heaters provide for 50% to 80% of the water heating demand. By installing solar thermal systems coupled with high-COP water source heat pump water heaters, the 20-50%

energy that the solar thermal collectors typically do not produce can be produced at extremely low electric energy consumption utilizing the heat pump. For example, a water-to-water heat pump with a COP of 5.0 combined with a 50% solar fraction system should effectively save 90% of the water and space heating energy, on average. During hot summer months, when solar thermal collection is most efficient, associated electric loads can be locked out to prevent any demand during critical peak periods. During winter days, solar collectors can heat water more efficiently for space heating or potable use or boost the effectiveness of the heat pump.
Combining solar thermal, heat pumps, PV and electrical storage has the potential to result in homes that are free of fossil fuels and potentially zero or even positive net energy. This would necessitate all appliances, such as clothes dryers, ovens & ranges, be powered by electricity preferably from a PV source. For such all electric homes, utility companies or developers should be able to avoid the expense of providing gas service to new developments, and the homeowners would benefit from reduced fire risk insurance costs.

Stakeholders
Potential benefiting stakeholders include:

- Utilities
- Homeowners
- Businesses
- Developers
- Environmental Organizations
- DOE
- EPA
- CPUC
- CEC
- CARB
- Cities & Counties

Background and the State-of-the-Art
UCSD: Geothermal Heat Pump Water Heater, Final Report (Energy Innovations Small Grant Natural Gas Program grant # 56957A/10-04G)

Prototype. Lab tests and field tests were done on a system not involving solar thermal collectors. Solar thermal integration and other design improvements such as a smart control integration are needed. Testing was done without solar or smart controls.

The three demo systems failed to exceed the goal COP of 4.0. It is felt that adding thermal migration prevention (check valves), better insulation and smart temperature controls will significantly improve performance. Also, adding solar thermal collectors will reduce the energy needed and boost the COP of the heat pump substantially.

CSI Thermal Program provides rebates for solar water heating, and soon, combination solar water and space heating. Public interest in combisystems is growing, but is not

yet directed toward the biggest economic and environmental benefit.

Justification
o From 2008 Long Term EE Strategic Plan, 12.6 million households, using 4,914 million therms gas, of which 790 therms per household is for water and space heating. A KEMA-Xenergy #SW063 study found solar water heating alone can save 830 million therms/yr. Efficient water heaters could save 80 therms.yr. The technical potential for SWH plus EE water/space heat is far higher than any EE measure.

o 910 million therms, residential, plus multifamily savings

o To be determined (assumed very large)

Ratepayer Benefit (Check one or more.)
x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

2. Building End Use Energy Efficiency

Issues and Barriers

The biggest users and losers, of low efficient energy, specific for natural gas high consumption are the urban buildings, in which the thermal and electric energy, and water systems is not integrated in an optimized combined and synergetic systems, to generate, reduce loses, capture each thermal energy loses, from heating, air condition, water, and electric consumption.
Each building, all cities are vulnerable to potential energy, water, crisis, by calamities, floods, earthquakes, hurricanes, potential terrorism demonstrated each years in our nation and in the world, resulting continuous multi billion-trillion national economic disasters.
The energy dependence from central power systems, and lines of power transmission and distribution by air power lines, always damaged by extreme weathers, is a demonstrated continuous repeated potential crisis.

Initiative Description and Purpose

Our top Absolute Maximum Efficiency Direct Thermal Energy Conversion in Electric Energy, is the unique, and final culmination of the science of thermodynamics and energy revolution, results of 30 years secrete military top absolute development and demonstrations, reached the Carnot-Paul-Yunkers cycle 90% electric efficiency and additional thermal CHP pure water cogeneration, totaling near 100% effective economic result of using the natural gas in each building, of California creating ALL OUR CITIES economic synergetic integrated independent energy and economic revolution, including millions jobs creation.
Our integrated synergetic universal distributed power-water- CHP is making any building and all cities economic giant self sustained, self financed, and giant jobs systems, for total independent security social economic systems, with unlimited prosperity.

Stakeholders

The patented GLOBAL PCT(Patent Cooperation Treaty) patent ownership, is our personal patent with divided intellectual properties with Defense Department, received from us the prestigious none exclusive license for military application only, and we have the worldwide unlimited rights for universal applications.
The Natural Gas and Energy Corporations, each building and all cities are the ideal partners, Stakeholders of this giant energy and economic revolution.
Current initiatives for unlimited international global cooperation are on the way, starting new era of cooperation and export from California to the world, and massive co funding opportunity.

Background and the State -of the- Art
Installation of our thermal electric generators, on top of all buildings, with ZERO FOOT PRINT, for the production of electric energy, and hot PURE water, by the rise of the natural gas on the top, and return to the ground the hydraulic colon of the gravitational hydraulic energy will create additional, clean renewable, and zero cost, 100% pure income, is 100% efficiency economic gift from GOD, electric energy on the bottom of the building, by hydraulic turboelectric generators.

Our thermal electric<<< Direct conversion of thermal energy in electric CHP energy >>>basic military fundamental research and development, is offering ready NOW for large development of new general urban energy self FINANCIALLY sustainable base with near zero emission, a total general energy independence and economic explosive prosperity, of our cities, generating multi billion –trillion self revenue, and jobs creation, for unlimited and eternal new era of total salvation.

Justification
NOW for this revolution is the hopeless economic crisis generated by the continuous terrorism of petroleum prices, with manipulation of all the world economy in hand of the darkest forces to dominate the world by uncontrollable hostile to world life and civilization. The maximum absolute demonstrated efficiency READY NOW TO PRODUCE and the instant availability is the guaranty for immediate prosperity and eternal future of humanity. By starting NOW this revolutionary program by California, will be a stellar example for all our nation, under fiscal cliff, and giant unemployment. The initial extremely low investment for development, fabrication and installation of first batch of 10-30 groups, of 300-3000 kw thermal electric generators can be based on $10 million, with the co participation of private investors, owners of the buildings, which can self generate an immediate financial return for ever.

Name of Initiative:

3. Deep Retrofit Design and Installation Methods

Issues or Barriers
Deep retrofit and high energy efficiency designs for whole buildings often fail to deliver the promised performance due to known issues with implementation, especially failure to measure performance of the system early enough to correct hidden installation deficiencies. Research is needed to support further development, demonstration and implementation of deep retrofit design and installation methods to reliably achieve the savings potential of energy efficiency strategies for homes and businesses.

Description and Purpose
The purpose of this work would be to reduce overall costs of implementing deep retrofit strategies in new construction and retrofit applications, demonstrate the integrated installation and measurement methods in additional applications, and train both industry leadership and key implementers on cost-effective and high impact techniques for realizing the potential of deep energy retrofit strategies critical for successful implementation of the California zero net energy building strategy.

Stakeholders
Residential and commercial building owners will benefit from application of deep retrofit designs and installation methods that achieve promised energy savings reliably. Society will benefit from reduced fuel use and corresponding reductions in greenhouse gas and criteria pollutants, contributing to a cleaner environment.

Background and the State-of-the-Art
Homes and businesses in California use an estimated 6.8 billion therms annually. 40% to 70% reductions of annual heating and cooling energy have been demonstrated using integrated installation and measurement methods and deep retrofit strategies in California homes. Such strategies are critical for helping California achieve its zero net energy building goals. However, the cost of providing these retrofits and the need for motivated, trained implementation stakeholders has severely limited the application and impact of these strategies. Significant work remains to be done related to reducing overall costs of implementing these strategies in new construction and retrofit applications, demonstrating the methods in additional applications, and training both industry leadership and key implementers on cost-effective and high impact techniques for realizing the potential of deep energy reduction strategies.

Justification
Benefits of this work will accrue to gas consumers and society. Consumers will benefit from better comfort, better indoor air quality and a safer, more durable home which uses much less energy. Society will benefit from reduced primary energy consumption and associated greenhouse gas emissions. Increased application of these techniques will also result in job creation for the building energy performance industry.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

4. **Next Generation High Efficiency Water Heaters**

Issues or Barriers
Current product offerings for high-efficiency gas water heaters are limited to thermal efficiency of approximately 95% using conventional combustion and heat exchange designs. Research is needed to support development and demonstration of next generation gas water heating equipment that incorporates advanced thermodynamic cycles to achieve thermal efficiencies of 150% or higher.

Description and Purpose
The purpose of this work would be to reduce the first cost of next generation high efficiency water heaters through design refinements and to ensure reliability in service over the lifetime of the water heater through key component design and testing.

Stakeholders
Residential and commercial operators of water heating equipment will benefit from commercialization and use of safe, reliable ultra-high-efficiency gas water heaters with reduced life cycle costs. Manufacturers of water heating equipment will benefit from increasing their high end product offerings at competitive prices. Society will benefit from reduced fuel use and corresponding reductions in greenhouse gas and criteria pollutants, contributing to a cleaner environment.

Background and the State-of-the-Art
According to AHRI shipment data, there are approximately 2.4 million residential water heaters that consume about 950 MMtherms annually. There are also 100,000 gas-fired commercial water heaters shipped a year. However, there are no commercially available ultra-high-efficiency water heaters on the market. Ongoing RD&D supported by the US DOE and the natural gas industry is showing encouraging progress, but significant work remains to be done related to product design, development, and testing before such products are ready for successful commercialization.

Justification
Benefits of this work will accrue to the gas industry, its customers, and society. The gas industry will benefit by being able to provide reliable advanced high efficiency gas-fired equipment options. Consumers will benefit from more energy efficient, cost-effective, reliable and durable gas products. Society will benefit from reduced primary energy consumption and associated greenhouse gas emissions. Identifying and resolving water heating technology and market issues will help the gas industry maintain viable gas water heating options in the future that meet customer expectations for cost, safety, reliability, efficiency, and performance while complying with the letter and intent of current and future regulations.

Ratepayer Benefit

x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative:

5. **Technology Advancements in Gas-fired Commercial Food Service Equipment**

Issues or Barriers

Commercial foodservice (CFS) represents a significant commercial energy savings opportunity, but barriers within the industry have resulted in technological advancement lagging behind other areas of energy usage. The barriers to the technology development and commercialization are technological and behavioral in nature related to concerns of equipment first costs and maintaining existing cooking characteristics. Financial barriers have been largely addressed by the willingness of some utilities to offer rebates for high-efficiency equipment; however the lack of data for qualifying equipment as high-efficient and the general lack of equipment being developed as high efficient has limited the effectiveness of these programs. The current consumer and utility awareness of energy efficiency and greenhouse gas emissions has cleared the way for higher-cost technologies to compete with standard product with a reduced first cost difference after the rebates are applied. The rebates and energy savings offered by these units create an attractive payback for the restaurant owner and provide a catalyst for this technology development effort. But for this to happen, the general technological state of gas-fired commercial foodservice equipment needs to be advanced in terms of energy efficiency and emissions (i.e. NOx and particulate) while maintaining exists standards for cooking quality.

Description and Purpose

The purpose of this work would be to advance the technology within commercial foodservice with modern blower, burner and controls for improving efficiency and emissions while maintaining existing cooking quality.

Stakeholders

Commercial operators of CFS equipment will benefit from commercialization and use of safe, reliable high-efficiency gas equipment through energy cost savings and improved heat distribution for cooking. Manufacturers will benefit from increasing their high end product offerings at competitive prices and improving general reliability. Society will benefit from reduced fuel use and corresponding reductions in greenhouse gas and criteria pollutants, contributing to a cleaner environment.

Background and the State-of-the-Art

On a per restaurant basis, the energy savings for a single more efficient cooking appliance are not substantial enough for the restaurant owner to be willing to pay a higher purchase price -- particularly for individually owned or small chain restaurant chains (50% of the CFS industry). Large chains have recognized the savings and advantages of efficient appliances and have driven their development. However, most CFS appliances do not have a high presence within larger chains, and thus no end-user driven incentive to develop more efficient designs. Without the backing of larger chains,

manufacturers currently lack the resources to either develop designs for or test advanced appliances. As a result, average efficiencies for CFS equipment is less than 30% and has changed little over the past few decades. One of the few exceptions has been fryers that have improved efficiency by over 50% in the past decade due to chain based influences on the industry. But most other gas appliances have had very little improvement in energy efficiency. Also, due to the lack of funds and incentives, very little work has been done on improving emissions such as particulate and NOx in the CFS industry. Manufacturers do not currently measure or manage NOx emissions of their units.

Justification

Based on information from FSTC, over 100 million therms could be saved in California with improved CFS equipment designs. But as discussed in the Background section, to get advanced CFS appliances to market would require support from other entities outside the CFS industry like the gas industry and government based research funds. Only collaborations between these organizations and technology based research firms provide the means for CFS equipment manufacturers to develop advanced appliances, as well as quantitative information about their savings. Significant work remains to be done related to product design, development, and testing before such products is ready for successful commercialization.

Ratepayer Benefit

x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative:

6. **Low NOx , High Efficiency Combustion for Residential and Commercial Equipment**

Issues or Barriers
Adverse impacts on combustion stability, increased costs, flame quenching, reduced equipment life, increased combustibles emissions, reduced efficiency, and flexibility.

Initiative Description and Purpose
Develop and demonstrate combustion concepts that can achieve NOx levels below 5 vppm at 3% O2 in commercial and residential applications, without adverse impacts on combustion stability, other pollutant emissions, efficiency, equipment life or costs.

Stakeholders
Commercial and residential energy users, equipment suppliers and installers; R&D organizations, including universities and natural gas utilities.

Background and the State-of-the-Art
Fuel and air staging or high excess air, together with improved fuel-air mixing and innovative combustion zone manipulations are techniques researched/developed to reduce NOx emissions from smaller burners. These techniques can lead to combustion instabilities, elevated emissions of CO/unburned hydrocarbons and, in the case of high excess air, a significant reduction in thermal efficiency and increase in equipment size and air blower power requirements, and flame flashback with premixed combustion

Justification
Increasingly strict NOx emissions regulations require development and deployment of cost effective, safe and reliable combustion techniques that can provide NOx levels below 10 vppm in residential and commercial equipment.

Ratepayer Benefit
Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initative:

7. Commercial Building Gas Use Initiative

Issues or Barriers

Commercial buildings in California (CA) use 12 hundred million therms of natural gas annually (CEUS 2006), and the commercial building sector is growing faster than any other type of building sector (CBECS). In order to meet CA's commitments to reduce carbon emissions by 25% by 2020, and 80% by 2050 (AB32), a significant proportion of the existing commercial building stock will need to be retrofitted to adopt low carbon HVAC strategies. The potential energy saving from retrofitting existing buildings greatly exceeds potential savings from new buildings. Prior efficiency retrofit incentives have often focused on incentivizing individual technologies rather than combinations of technologies that optimize the performance of whole buildings. To achieve its stated efficiency goals, CA will need to focus its energy efficiency efforts where they will achieve maximum energy savings. Incentive priorities will need to be data driven, and reward deep retrofits that combine multiple self-reinforcing efficiency improvements. Potential targets for energy efficiency improvements of existing buildings include envelope performance, glazing performance, HVAC efficiency and envelope tightness. However, there is presently no comprehensive picture of the relative importance these factors play in our current CA gas energy use, or their sensitivity to statewide efficiency incentives. There is a clear need for guidance as to which efficiency incentives or combinations of incentives have the greatest per dollar impact on gas use. Without an improved understanding of heating energy losses in commercial buildings and incentive impacts, future investments in building energy efficiency may not be optimal.

Initiative Description and Purpose

This initiative will identify the main factors that determine gas use in CA; assess the relative impact of potential efficiency improvements which target combinations of these key factors; and provide guidance on the most cost effective incentives predicted to achieve the highest gas savings per dollar invested. The effort would make use of existing data on commercial buildings including the CEUS, CBECS, CBP and BASE surveys. New survey data would be collected on envelope tightness, and building component performance to supplement existing databases.

As part of a prior CEC study (Contract number 500-10-025), several hundred EnergyPlus models were developed to be representative of the existing CA commercial building stock. These models will be expanded upon, using both new and existing survey data. They will then be used to perform a parametric analysis, identifying which factors are most significant in driving gas use, and their relative significance. These factors include, but are not limited to, envelope air leakage, conductive envelope losses, glazing losses and HVAC inefficiency. Combinations of efficiency improvements will be identified that provide optimal energy savings per dollar of retrofit cost. Analysis will be performed on a range of potential statewide incentives and changes to standards, with the objective of identifying measures with the greatest impact per dollar.

Stakeholders
CA commercial building operators will be the principal beneficiaries of the gas use savings from this initiative. Secondary benefits include a statewide reduction in gas consumption, with likely implications for domestic gas prices, outdoor air quality and lower state carbon emissions.

Background and the State-of-the-Art
Prior research indicates the significant energy saving potential of retrofitting commercial buildings. Analysis by Itron (2006) estimated natural gas usage for California at 2,070 million therms, and the technical potential for savings at 109 million therms. This analysis included only HVAC and other equipment and did not investigate the savings from envelope measures such as those this project proposes to investigate. This exclusion of envelope measures from potential natural gas savings estimates is common. A meta-review from Pacific Northwest National Laboratory (PNNL 2009) summarized findings from six large energy efficiency studies and found that roofs, walls, and foundations were excluded from all. The savings from window retrofits were examined in only one of the studies. The Advanced Energy Retrofit Guides (DOE 2011) provide general project planning guidance to help building owners, facility managers and energy managers select the best energy efficiency measures for their building type and location. The guides provide an overview of energy retrofits and potential energy savings from various retrofit measures, but do not serve well as a guide for the development of future standards and incentives.
There is growing recognition that changes in the structure and scale of incentives will be necessary to achieve mandated efficiency goals. The Institute for Building Efficiency has proposed a new incentive structure, Deep Energy Efficiency Pays (DEEP), which proposes providing additional funds on top of individual rebates for projects that meet a specified threshold of whole building energy savings. However, no prior studies have been identified that assess the cost benefits of such incentive structures, if applied in CA.

Justification
In order to meet the goals laid out in the California Public Utilities Commission's Energy Efficiency Strategic Plan (CPUC 2008) of achieving NetZero energy in 50% of CA's commercial buildings by 2030, a significant shift will be required in the current approach to incentivizing deep building retrofits. New strategies will be required to encourage the necessary depth of retrofits, in a sufficiently large proportion of CA's commercial buildings. The results of this proposed incentive will inform the necessary changes in building codes and standards required to make this transition. The success of this undertaking could potentially deliver in excess of 6 hundred million therms of natural gas savings, and put CA on the path towards a low carbon future.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety

x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

8. **Calstat: A Thermostat Designed for California's Homes**

Issues or Barriers

California's homes present special challenges for thermostats and related controls. The climate is mild which, when combined with Title 24 requirements, leads to low heating and cooling loads. It is easy to overheat or overcool. A second challenge is highly irregular occupancy patterns, causing scheduled programs to heat and cool many empty homes. Recently, thermostats designed to "learn" the occupants' schedules have been introduced; however, they have difficulty successfully converging to efficient heating/cooling solutions. Finally, California homes will soon face electricity tariffs that strongly encourage conservative operation during peak events. The combination of these conditions suggests a need for a different kind of thermostat – and possibly even the underlying logic—in California homes.

Initiative Description and Purpose

We propose to develop a residential thermostat specifically tailored to California's unique conditions. This California-oriented thermostat—we propose the name "Calstat"– would enable significant energy and peak power savings and lower consumer frustration. The project's eventual goal would be a prototype Calstat, although the first stage might be a combination of specifications and algorithms suitable for adoption by manufacturers of thermostats.

Stakeholders

Consumers would naturally be the greatest beneficiaries of a more user-friendly and energy-saving thermostat. However, California utilities and regulators would also benefit through acquisition of low-cost energy and emissions reductions. Calstat would harness or enable energy-saving behavior not otherwise available.

Background and the State-of-the-Art

A research company has explored usage patterns of modern, programmable, thermostats, including occupant success at achieving specific tasks. Various California firms, such as Herter Engineering (funded by SMUD and the CEC), have assessed the effectiveness of different thermostats and home energy displays. UC Davis, with funding from SCE, has examined usability of thermostats in small commercial establishments. Researchers developed techniques for quantifying usability in thermostats. Researchers have developed several prototype thermostats to accommodate time-of-use pricing and to improve usability. Recently, Nest Labs (Palo Alto) created an entirely new type of thermostat, relying on occupancy sensing and learning algorithms. Even this design has significant drawbacks in the California conditions described earlier, so Nest Labs (and other manufacturers) are targeting relatively cold or hot climates. DOE's research programs to build homes with extremely low (or net-zero) energy use have encountered numerous difficulties with heating and cooling controls.

Justification
Calstat will provide Californians with a thermostat that makes intuitive sense for today's homes and lifestyle while saving natural gas. The maximum technical potential savings is roughly 110 million therms per year for single-family homes. Further savings may occur outside California.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
  GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

9. **Fixing the Classroom Ventilation Problem**

Issues or Barriers

A growing body of data indicates a serious problem of inadequate outdoor air ventilation in California's, and other state's, classrooms (CRs). Based on a state-wide survey ~50% of CRs have less outdoor air ventilation than required by codes, with many CRs having far less ventilation than specified in codes. Research shows that low CR ventilation rates are linked to increased rates of illness absence and to reduced academic performance. Research in other types of buildings has found that a variety of acute health effects increase with low ventilation rates, these findings likely also apply to CRs. It is imperative that California address this widespread problem. Average ventilation rates will need to be increased, which will increase the energy required for classroom heating and cooling. Much of this heat is provided by combustion of natural gas.

Initiative Description and Purpose

The purpose of this initiative is to develop and help deploy the technologies and strategies needed to overcome the widespread problem of inadequate ventilation in California's CRs in the most energy efficient manner practical. The solutions must be appropriate to school districts with respect to costs and installation and maintenance requirements. One may be tempted to dismiss this initiative given the funding constraints faced by school districts. However, it is in district's financial interest to improve CR ventilation. In California, districts are reimbursed from the State based on days of student attendance. In a recent two-year study of approximately 200 CRs from three California school districts has shown that low ventilation rates increase student illness absence rates. Districts can expect increased revenue from the State as a result of decreased student absence, when they fix the problem of poor CR ventilation. The increased revenue is projected to exceed the increase in energy costs by a factor of five.

A variety of solutions will be required given the variability in climate and existing HVAC technologies serving CRs. Accordingly, the initiative should identify, test, and demonstrate a variety of technical solutions, some involving improved control of existing HVAC systems, some based on installation of supplemental equipment dedicated solely to providing CR ventilation, and some based on replacing existing HVAC systems with newer energy efficient products that provide the required ventilation while increasing energy efficiency. The initiative should assess technology energy performance, ventilation performance, and cost, and develop installation and maintenance guidelines. The effects of technology adoption on energy costs, student absence, and attendancerelated
reimbursements should be estimated for each school district. In addition, the initiative should investigate financial options to help school districts overcome the initial costs, which can be a barrier despite the expected large payback. All findings should be packaged and broadly communicated to school districts. The initiatve should be performed in partnership with a sample of school districts and with the school facilities

unit in the California Department of Education.

Stakeholders
Stake holders include: 1) the companies making and installing HVAC hardware for schools; 2) school districts; 3) the California Department of Education; 4) teachers; 5) students and their parents.

Background and the State-of-the-Art
A survey of California CRs documented the high CO2 concentrations indicating low ventilation rates. Based on these data, the estimated average ventilation rate is 4 L/s per occupant, while codes specify a minimum of 7.1 L.s per occupant. Two out of two studies have documented that low ventilation rates increase student absence, one was recently completed large study in three California school districts. Research from around the world (see www.iaqscience.lbl.gov), including the U.S., has shown that student performance as measured by various tests, including standardized tests of academic performance, suffers in classrooms with low ventilation rates. .A variety of technical solutions are available to address the problem of poor ventilation, but the best solutions need to be identified, demonstrated, and deployed.

Justification
California has 300,000 K-12 CRs housing 6.2 million students. Widespread poor ventilation increases risks to student and teacher health and has been shown to increase student illness absence and reduce academic performance. Increasing CR ventilation rates from 4 l/s per occupant (best estimate of current average) to the code requirement of 7.1 L/s per occupant is projected to increase annual revenue to school districts by $33m, diminish $80M in annual losses associated with parental care of children absent from school, and increase annual energy costs by $6.2 million ($3.2 million is for gas)

Ratepayer Benefit
Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
GHG emissions mitigation at the

Name of Initiative:

10. Controlling Ventilation Rates in Commercial Buildings

Issues or Barriers

The outdoor air ventilation provided to buildings intentionally and via unplanned air leakage increases heating and cooling loads, particularly the heating loads often met by combustion of natural gas. Ventilation is also critical for maintaining occupant satisfaction, health, and work performance; with diminishing returns as ventilation rates increase. Despite the importance of ventilation, data indicate that ventilation rates are very poorly controlled. In offices, average minimum ventilation rates far exceed code requirements at least by a factor of two, yet a significant number of buildings still have less ventilation than required by codes. In ~50% of classrooms, ventilation rates fail to meet code requirements, often by a large margin. In most other building types, data are sparse but minimum ventilation rates appear to exceed code requirements. Ventilation rates are poorly controlled, in part, because very few buildings have any sensorfeedback-
control system for building ventilation. Unplanned air leakage contributes significantly to poor control of building ventilation, particularly in small commercial buildings. When ventilation rates are excessive, heating energy is wasted. When ventilation rates are too low, occupant health and work performance are compromised.

Initiative Description and Purpose

The purpose of this initiative is to develop and help deploy the technologies and strategies needed to gain control of ventilation rates in California's commercial buildings. One task would identify, test, and demonstrate the best methods of sealing leaks in envelopes and duct systems in small commercial buildings so that uncontrolled infiltration contributes much less to poor control of ventilation. Novel air sealing technologies should be considered, such as extending the aerosol based duct sealing technology developed to building envelopes and application of foam insulation to seal and insulate in one step. A second task would develop, evaluate and demonstrate approaches for demand controlled ventilation (DCV). Currently, DCV, when applied, relies on CO2 sensors. While prior research found that this technology was failing due to sensor inaccuracy, manufacturers claim to have improved their sensors. Novel potentially lower cost approaches that do not rely on carbon dioxide sensors should be investigated. An examples is RFID sensing of employee badges, a very common technology, to provide a signal for ventilation control. To protect employee privacy, RFID signals need not be linkable to individuals. A third task would develop, test, and demonstrate new hardware systems for continuously measuring rates of outdoor airflow into air handlers. The fourth task would evaluate, and develop as needed, technologies for use by air balance companies to measure rates of airflow into air handlers during period air balancing sessions. All tasks should be performed in partnership with industry partners so that at the end of the project industry can rapidly bring products to market.

Stakeholders
Stake holders include: 1) the companies making and selling hardware needed to control ventilation rates such as manufacturers of CO2 sensors, velocity sensors, RFID technologies; HVAC manufacturers, HVAC system designers; building owners, managers and operators; air balance companies; the general public.

Background and the State-of-the-Art
Surveys supported by various institutions have collected sufficient ventilation rate data to document the very poor control of building ventilation rates, and the significance of air leakage, particularly in small commercial buildings. Research from around the world, including CEC supported research, has documented that ventilation rates affect health, work performance, and absence rates. DOE supported research at LBNL has evaluated most of the existing products for continuously measuring rates of airflow into air handlers and shown that existing products are not adequate. DOE, CEC and others have supported tests of CO2 sensors for demand controlled ventilation and identified large accuracy problems. This prior research motivates and sets the stage for solutions.

Justification
This technology is applicable to the full commercial building sector in California that uses 4.8 x 108 therms of gas per year for heat (4.2 x 108 therms excluding schools). Simulations by NREL indicate that ventilation uses 21% of natural gas in the existing building stock. Since minimum ventilation rates in offices, which use 1.4 x 108 therms of gas for heat, are, on average, twice requirements, the potential savings are 10.5% (half of 21%) of 1.4 x 108 therms, or 1.4 x 107 therms per year.in offices. For the full commercial stock excluding schools the potential savings is 4.2 x 107 therms per year, but uncertainty about existing ventilation rates make this a rough estimate. In classrooms, gas energy use would approximately double, increasing by 4 x 107 therms per year, small relative to the savings in other buildings. Improved ventilation in schools would improve student health, reduce absence, and improve academic performance.

Ratepayer Benefit
Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

11. Effective Residential Wall Insulation Retrofits

Issues or Barriers

The addition of thermal insulation to existing residential building assemblies is a key component of statewide efforts to reduce home energy use. Yet, some of the most well respected home performance contractors in California avoid insulating existing walls based on concerns over moisture and durability problems. Many existing CA homes do not have adequate weather resistive barriers or moisture detailing around windows, doors and other penetrations; these conditions results from improper construction and from degradation of materials over time. The problem is exacerbated by minimal or nonexistent roof overhangs, e.g. for parapet roofs. The impact of water intrusion into wall cavities of existing homes historically has been mitigated by the relatively open pathway for drying in un-insulated walls combined with long drying times during most CA winters. Adding insulation can substantially increase the time required for drying and increase the frequency and duration of moisture retention; this then increases the risk of moisture damage. With a lack of data and clear guidance, home performance contractors are taking the “do no harm” approach of avoiding insulating any wall for which they cannot ensure adequate weather barrier. The cost is either a lower-performing retrofit or a much more expensive retrofit that includes siding or stucco removal.

Initiative Description and Purpose

The first step in addressing this concern is to conduct research to assess and quantify the scope of the problem. Data are needed on the quality of the existing building stock, specifically focused on how common are wall assemblies that allow moisture intrusion and the moisture levels that prevail in the framing members of these walls. We also need data on the impact of insulation on drying under the range of conditions that prevail throughout the state. Long-term monitoring of walls that have been insulated is also needed. Data collection should occur through surveys and suitable protocols to ensure integrity of the assessment. The application of hygrothermal simulation models to a variety of documented common problems in existing wall assemblies will complement the empirical approach. A second major area of effort is in the development of guidance for home performance contractors. At the initial stage, this could focus on development of diagnostic tools and calculators to help contractors identify walls that should not be insulated without repair or retrofit of the drainage layer. A third area of R&D is to develop lower-cost solutions to improving wall cavity insulation practices while limiting the risk of moisture-induced damage.

Stakeholders

Home performance contractors; Insulation contractors; CA homeowners; Energy efficiency programs and government agencies promoting wall insulation

Background and the State-of-the-Art

Drill-and-fill wall insulation has become common practice in the home performance industry without sufficient evidence of its long-term effects. The U.S. Department of Housing and Urban Development has identified moisture as the greatest threat to the durability and long-term performance of the housing stock, noting the lack of empirical knowledge about moisture related building damage (Dacquisto et al. 2004). The Moisture Management for Exterior Wall Systems (MEWS) project was a large-scale modeling exercise by NRC-CNRC to assess response of low-rise residential wall systems to general climatic conditions and rain entry (Beaulieu et al., 2002). A number of other efforts have investigated this issue, namely in high-rise construction, in masonry clad buildings in cold climates, as well as in the addition of exterior insulation in retrofit. The Building America program guidelines for air sealing and insulting walls in existing homes direct that if signs of water damage or moisture intrusion are observed, walls should not be insulated until the issue is remedied. At the same time, public health researchers have documented improvements in exposure to low indoor temperatures and high humidity levels resulting from home insulation retrofits. The repercussions of widespread wall insulation retrofits in CA are not clear from these past efforts.

Justification

There are currently many energy retrofits being implemented without wall insulation, or being done at very high cost, harming cost-effectiveness. Many homes being retrofitted with drill and fill wall insulation may be receiving benefits now at the cost of widespread building failures over the next several decades. In 2011, there were 9.5M single family homes in CA and about 75% were built prior to wall insulation requirements. If 20% of space heating could be reduced through wall insulation in all CA SF homes, annual energy reductions of 2,456 GWh could be achieved.

Ratepayer Benefit

x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative

12. Efficient control technologies for residential particulate exposure

Issues or Barriers

Current air quality standards rely on mechanical ventilation to control indoor generated pollutants because there has not been a clear indication of which pollutants caused indoor health impacts. Recent research has shown that PM2.5, on a population average, has the greatest health impact on chronic health in homes [1]. Filtration and air cleaning may be a more cost effective and lower energy use method of removing PM2.5 then ventilation, however the lack of data about the size distribution and composition of residential PM2.5 has prevented the optimization of filtration technologies for residential use. This study might allow us to trade off PM against other contaminants to achieve desired health outcomes at lower energy costs

Initiative Description and Purpose

The purpose is to characterize PM2.5 in a large number (500-1000) of CA residences by measuring particle mass concentration in different size ranges that are relevant to reported filtration efficiencies. The study will also evaluate the effectiveness of filtration systems in homes. The size distribution data will allow for the analysis of the effectiveness of reducing indoor PM2.5 of different filtration and air cleaning systems and potentially the design of optimized PM2.5 control systems. The cost of this initiative could be greatly reduced if this project were combined with some other field project for measuring IAQ. The proposed work will address need to evaluate PM mitigation proposals more broadly

Stakeholders

The California Energy Commission and individual home owners are stakeholders because reducing PM2.5 via filtration may allow for the reduction of the required flow rate of outdoor air in residential ventilation standards. This would result in a reduction in the required energy needed to heat the home. Homeowners are also stakeholders because reducing PM2.5 concentrations will improve their health. Air cleaning and filtration companies are stakeholders because they will be informed of what filtration parameters are needed to effectively reduce the PM2.5 concentration indoors. The results will provide the information necessary to design more efficient filtration systems.

Background and the State-of-the-Art

Providing a healthy indoor environment is a barrier to energy efficiency goals since currently the only indoor air quality standards are ventilation standards. Ventilation increases the heating and cooling energy demand. Alternative methods of improving indoor air quality may lead to a reduction in the needed amount of ventilation air to provide good indoor air quality. Recent work has shown that on a population bases, PM2.5 presents the greatest chronic health threat in US homes [2]. PM2.5 is both an indoor and outdoor pollutant meaning that ventilation can actually make the situation worse indoors. Reducing PM2.5 requires filtering incoming air and/or cleaning/filtering

the air in the home. The effectiveness of filtration and cleaning technologies varies as a function of particle size. A filter may capture larger particles easily, but not capture smaller particles. The particles making up PM2.5 vary from less than 100nanometers up to 2.5 micrometers in diameter. Comparing the effectiveness of different filtration/cleaning technologies requires knowing what fraction of the mass of PM2.5 is in each of the size bins of interest. This requires characterizing PM2.5 in the residential environment.

Justification

Chronic exposure to pollutants in indoor air has been estimated to cost, on average, $400-1100 annually per person in CA and the vast majority of that (>80%) was attributed to PM2.5 exposure [2]. Altering the CA housing stock to meet ASHRAE 62.2 (the prevalent residential standard in the United states) has been estimate to require over 500 kWh annually in tight homes and may not reduce the impact of PM2.5 on health of residents[1]. Determining the characteristics of PM2.5 in residences will allow for the comparison of different filtration technologies to determine how to most cost effectively, and with the least energy use, mitigate PM2.5 via filtration and air cleaning technologies. Implementing effective non-ventilation PM2.5 reduction technologies could reduce the required rate of home ventilation thereby reducing heating fuel use in natural gas homes.

Ratepayer Benefit

Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative:

13. Guidance on Indoor Environmental Quality in Multifamily Retrofits

Issues or Barriers

Retrofits in multifamily buildings provide a vital opportunity to improve the health and comfort of the one-third of Californian households who live in them. Yet, indoor environmental quality (IEQ) is often not addressed in multifamily retrofits. Contractors who are knowledgeable on energy efficiency measures often encounter issues outside their expertise, such as moisture and molds, air exchange between units transfering odors, cooking fumes, environmental tobacco smoke, etc. These are challenges that impose risk and deter multifamily buildings from retrofitting.

Initiative Description and Purpose

This initiative aims to develop guidance on IEQ for multifamily retrofits. The work will include surveying of major types of multifamily residences, collect IEQ and building performance data, and utilize the data to develop IEQ guidance for retrofit projects. Past research on Apartment Retrofits for Energy and IEQ funded by CEC PIER identified poor maintenance, overcrowding, inadequate ventilation, exposure to combustion contaminants drive some of the major health concerns in multifamily homes. This initiative aims to expand the scope to consider multifamily buildings of various types beyond low-income housing. The guidance will include determining the ventilation needs for different types of multifamily buildings, and demonstrate the potential health benefits that can be achieved by retrofit programs. Contractors and auditors can rely on the data and guidance generated from this work to perform energy upgrades that will also improve IEQ in multifamily homes. The added health and comfort benefits to occupants will motivate their cooperation and encourage building owners to participate in retrofit projects.

Stakeholders

This initiative will benefit one-third of households in California who reside in multifamily buildings, of which a significant portion of them are lower income renters. Development of the guidance document will involve many stakeholders in the process, e.g., contractors, utilities, building management, standard and training organizations, local and housing agencies. By providing much needed information on addressing IEQ in addition to energy savings, this initiative will promote more retrofit projects in the multifamily sector.

Background and the State-of-the-Art

Whole-building performance approach in retrofits means to consider a suite of energy efficiency measures including heating, cooling, water heating, appliances, and lightning. However, an important element that is still missing is indoor environmental quality (IEQ). At the ACI California Home Performance Conference 2012, there were discussions on many health and safety issues faced in multifamily retrofits. This highlights the lack of

data on IEQ in existing multifamily buildings, and guidance on how they should be addressed in retrofit programs. Multifamily buildings are particularly vulnerable to poor IEQ due to high occupancy, connection between units, common areas, split incentives between the building owners, managers, and occupants. Many of the IEQ concerns are linked to natural gas usage in cooking, space heating, and hot water, forming combustion products, moisture, and odors that pose health risks to occupants. Providing adequate ventilation and minimizing air transfer between units are two opportunities that multifamily retrofits must address in order to improve IEQ. The ventilation standards in multifamily buildings need to be reviewed. Problems such as moisture and molds, exposure to harmful combustion pollutants, can be prevented by providing adequate ventilation and effective exhaust in kitchen and bathroom. While research on the ventilation needs of single-family detached homes and commercial buildings exist (i.e., Residential Energy Savings from Airtightness and Ventilation Excellence (RESAVE) and Healthy Zero Energy Buildings (HZEB), both research programs are funded by CEC PIER), multifamily buildings are unique because of high occupancy and the potential interaction between units on airflow and contaminant transport. As a result, there is a need to collect data from the major types of multifamily buildings to evaluate if the current guidelines, which are largely based on residential standards meant for single-family homes, are adequate for multifamily buildings.

Airtightness is currently not a key focus of multifamily retrofit programs partly because testing protocols that are commonly used do not generate the data needed to obtain energy credits. For example, RESNET test procedure requires measuring the airtightness of each unit in a multifamily building. Testing unit-by-unit is more ractical than whole-building testing because the latter requires access to all units at once. Airtightening each unit is also beneficial to managing IEQ by isolating them from pollutant sources emitted from other units. Data synthesis from this work can show the benefits of reducing airflow between units beyond just the energy savings from airtightness improvements.

Justification

A recent report "*Improving California's Multifamily Buildings: Opportunities and Recommendations for Green Retrofit & Rehab Programs*" (2010, draft) by MF HERCC estimated that if 14% of the 2.4 million multifamily units in California were to improve their energy performance by 25%, this would reduce energy consumption by 37 million therms. In addition, there are large societal benefits through improving the health of Californians who reside in multifamily buildings. A larger fraction of the occupants in multifamily homes are low income, and often they are renters. By removing the barriers to multifamily retrofit programs, this initiative will benefit many in Californians who otherwise have little control over the energy efficiency aspects of their homes.

Ratepayer Benefit

x Promote greater reliability
  Lower costs
x Increased safety

x Societal benefits
GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative

14. Indoor Air Quality monitor to enable health-based ventilation

Issues or Barriers

In order to ventilate homes effectively while conserving energy, it is critical to be able to identify when indoor air quality (IAQ) is problematic. While natural gas provides an efficient fuel choice compared to electricity, natural gas appliances do increase the emission of indoor contaminants. Ventilation has been shown to be effective at removing indoor contaminants from both diffuse and localized pollutant sources, but we do not always ventilate in the most effective ways. In the kitchen, for example, range hoods can capture the majority of contaminants from stovetop cooking, but only 10 to 25% of households always use range hoods when cooking1. Other than odors (to which occupants can quickly become acclimatized), visible mold growth, and occasional smoke or carbon monoxide alarm soundings, residents have little feedback on their indoor air quality.

Initiative Description and Purpose

This project will develop an IAQ monitoring device to quantify residential air quality for ventilation control, similarly to how a thermostat monitors temperature to control heating and cooling systems. Such a device could be used to motivate occupant use of range hoods and bathroom exhaust fans or the device could be used to control mechanical ventilation systems to operate when most needed. Current CEC-supported research to determine indoor contaminants that pose the greatest risks to occupants would help us to determine which contaminants to monitor to provide the best metrics of indoor air health. Contaminants monitored could include carbon monoxide, particulate matter and carbon dioxide. The project would include the design of a device with embedded sensors that would display contaminant levels. Real time feedback from the device could then help occupants understand cause and effect of different emission events and control actions. If the project is successful, funding for an additional year to do more extensive field testing would be sought.

Stakeholders

California Energy Commission/Title 24, ventilation and controls manufacturers

Background and the State-of-the-Art

Some products do exist to monitor indoor air quality, but there is little understanding of the impact of indoor air quality feedback on occupant or mechanical control of ventilation. In a study of 14 homes, Kim and Paulos used touchscreen devices to measure and display a time trace of particulate levels2. They found that residents continued to engage with the displays over the 4 week study period and reported that seeing spikes in the signal prompted actions to reduce contaminant levels. Carbon dioxide meters are used to control ventilation rates in commercial spaces with high, intermittent occupancy such as lecture halls, but IAQ-controlled ventilation in residences is very limited. The proposed work complements recent CEC studies on range hood

capture efficiency. Recent reduction in costs for wireless sensing increases the possibilities for monitoring and feedback systems at this time.

Justification

If we can identify when and where in a home it is most important to ventilate in order to remove contaminants with the greatest health impacts, we can improve indoor air quality while reducing the energy costs to ventilate. In 2006, residential use comprised 22% of California's 6,032 MMcfd of natural gas, of which about 44% is due to heating3. We know that key contaminants in California homes are products of combustion and cooking, formaldehyde and particles. If successful, this monitoring project could increase ventilation costs. However, the benefits associated with improved air quality outweigh increased ventilation costs4. Based on measurements in homes nationwide, illness and death due to indoor air quality translates to costs in California of 8 to 67 billion dollars annually 5. IAQ feedback has also indicated potential for reducing cigarette smoking rates6 leading to substantial health savings. Over the longer term, an IAQ monitor could allow for performance-based ventilation regulation in Title 24. The device could reduce the total amount of ventilation and thus energy required, by enabling occupants and mechanical devices to operate only when needed.

Ratepayer Benefit

Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative:

15. Integrated Technology Demonstration and Tools for Commercial Building HVAC Retrofits

Issues or Barriers

In 2011, commercial buildings in California used about 2 billion therms of natural gas and about 100 TWh of electricity (http://ecdms.energy.ca.gov/). Heating, ventilating, and air-conditioning (HVAC) systems are the largest energy consumer in these buildings (about 40% of the sector primary consumption based on national values). Although the energy efficiency of many HVAC components has substantially improved over the past 30 years (e.g., chillers), there are still deficiencies in other critical components (e.g., air handling systems, which provide heating and cooling to occupied spaces). There is no single cause for current deficiencies. One cause is that the design and construction industry is generally unaware of the large performance degradations caused by deficiencies, and consequently problems have received little attention. Part of this problem is due to the lack of reliable data from measurement and verification (M&V) activities. Other causes include poor installation quality and inadequate analytical tools for designers. The highly fragmented nature of the building industry means that progress toward solving these problems is unlikely without leadership from public agencies such as the California Energy Commission (CEC). Separate, proven technologies already exist that each can save 10 to 50% of HVAC system energy depending on the type and magnitude of the deficiency they address (e.g., sealing system leakage, duct static pressure reset, wireless conversion of constant-air-volume systems to variable-air-volume, demand-controlled ventilation). Many of these technologies use innovative approaches that also provide enhanced system control and monitoring capabilities. When implemented together, these technologies will interact so that the resulting savings are likely larger than those achieved by any single technology, but less than the sum of the individual savings. Using these technologies to retrofit existing air-handling systems so that they use as little energy as possible while still providing acceptable indoor environmental quality (IEQ) will help the State achieve its building end use energy efficiency goals.

Initiative Description and Purpose

Our goal is to enable cost-effective energy consumption and demand reductions in California commercial buildings through integrated implementations of air-handling system retrofit technologies (described in “Background and the State-of-the-Art” section), without adversely affecting building serviceability or the environment. The first objective is to carry out a combined technology demonstration that: a) quantifies energy and environmental costs and savings, and b) shows that IEQ can be maintained or improved at the same time. A second objective is to transition the integrated technology package to a broader scale through a public-private partnership to provide guidelines and user-friendly screening/analysis tools that can be used in the future to identify and address similar energy saving opportunities at other sites throughout California.

The project team will test up to five candidate large commercial buildings in California to roughly assess air-handling system leakage and mechanical ventilation airflows; the selected test building will have significant leakage and apparent over-ventilation. After developing and submitting a detailed demonstration plan for approval, the team will install and commission M&V instrumentation (including sMAP) needed to perform baseline monitoring of the building's whole-building energy use (natural gas and electricity), air-handler heating and cooling loads, fan energy, and IEQ, which includes monitoring CO2, absolute humidity, particles, and selected volatile organic chemicals (VOCs). Monitoring will then occur for at least four months, or until sufficient data have been collected to characterize the seasonal baseline system performance.

In parallel with baseline monitoring as performance data become available, the team will design the air handling system retrofits. This step will include addressing technology integration issues and opportunities that may arise. Next, each of the three primary technologies will be installed and commissioned. Building monitoring will then resume for at least four more months, or until sufficient data have been collected to characterize post-retrofit seasonal performance relative to the baseline. Energy savings cannot be determined by simply comparing pre-sealing and post-sealing energy use, especially when substantially different weather conditions occur in the two monitoring periods. To minimize weather effects, simple regression models based on correlations between weather conditions, time of day/week, and building energy use during the pre-retrofit period will be developed. These models will then be used to predict the energy that the building would have consumed under post-retrofit weather conditions had it not had a retrofit.

Energy savings then will be the difference between this predicted consumption and that actually measured post-retrofit. M&V analysis techniques that are being developed now for implementation in Pacific Gas and Electric's (PG&E) Universal Translator (UT) software tool will be used where possible. An advantage of using the UT is that it allows us to more easily address uncertainty issues in our analyses. To estimate annual energy savings for a typical weather year, we will develop another set of regression models for the post-retrofit period to simulate building energy use. Annual building energy use under pre- and post-retrofit conditions can be predicted using these models and typical meteorological year (TMY) weather data. Annual energy savings then will be the difference between annual energy use with pre-retrofit conditions and that with post-retrofit conditions. A similar approach will be used to assess retrofit impacts on IEQ, as indicated by monitoring CO2 and absolute humidity (as well as by VOC and particle concentrations).

We will use the initial screening data together with the detailed monitoring data to develop guidelines and easy to use, simple electronic tools that will support building screening and to estimate energy savings potential and IEQ impacts from applying these retrofit technologies. These guidelines and tools will be provided to energy managers, designers, and contractors in at least two short half-day courses on developing energy projects that potentially could utilize these technologies. Also, through events such as GovEnergy, we will disseminate results to energy service companies (ESCOs) and utilities. Finally, by publishing peer-reviewed papers, we will inform a broader range of other entities about the project results.

Criteria for success include: 1) identification and capture of 40 to 50% HVAC energy saving opportunities related to integrated air-handling-system retrofits, 2) maintenance or improvement of IEQ, and 3) development of guidelines and simple tools to facilitate broad scale applications throughout California.

Stakeholders

Stakeholders affected by the proposed work include building owners, occupants, and facilities staff; designers, contractors, and commissioning agents; energy service companies (ESCOs); code officials; electricity and gas utilities; technology vendors; and financial institutions.

The following organizations and people have expressed interest in carrying out this project (their availability to participate needs to be reconfirmed if the project moves forward). Lawrence Berkeley National Laboratory (Craig Wray – Principal Investigator plus integration and modeling lead, Mike Sohn – M&V IEQ and optimization lead); Western Cooling Efficiency Center (WCEC, Mark Modera – Aeroseal technology lead); Vigilent (Cliff Federspiel – technology lead); AirXpert Systems (David Bearg – technology lead); Building Robotics (Andrew Krioukov – sMAP technology lead, Abe Otham, Stephen Dawson-Haggerty – engineering support); Schneider Electric (Kevin Vaughn – M&V lead, Corey Newby – M&V support).

Background and the State-of-the-Art

Three state-of-the-art primary air-handling system retrofit technologies will be demonstrated simultaneously. One is Aeroseal's air distribution system internal sealing technology, which was developed at LBNL. The second primary technology is the Vigilent Intelligent Energy Management System, which uses multiple temperature, humidity, and pressure sensors placed throughout the building to provide data to a server through a wireless mesh network. Its artificial intelligence engine in turn modulates fan speeds to circulate only the air needed to achieve temperature and minimum airflow set points. It can convert energy-wasting constant-air-volume systems to variable-air-volume without installing terminal boxes or disturbing hazardous building materials. It can also be used to implement duct static pressure reset schemes without terminal box communication. The third primary technology is AirXpert's demand-controlled ventilation system, which adjusts outdoor air supply based on occupancy levels represented by multipoint shared-sensor carbon dioxide (CO2) concentration and dew point temperature (absolute humidity) measurements. The data collected also support diagnostic feedback about ventilation rates, effectiveness of overnight purges (if used), humidity control assessments, the potential for indoor mold growth, and infiltration of unconditioned air into occupied spaces. A fourth technology also will be demonstrated, but primarily to support M&V activities. sMAP for Buildings is a software solution that integrates and organizes the wide variety of data into a simple common representation for use in M&V, optimizing HVAC systems, and making building operation easier and more proactive.

All four technologies are mature and ready for demonstration today, pending building specific design work. Each has been separately implemented in buildings, but never together. In particular, the aerosol-based sealant technology is about 20 years old, and

was developed in part with California Energy Commission (CEC) funding. It was subsequently licensed to Carrier (now licensed to Aeroseal) and has been used for more than a decade to seal thousands of residential air distribution systems, hundreds of small commercial building systems, and several large commercial building systems. It has also been demonstrated at a dozen U.S. Department of Defense sites, some as part of the Navy's Techval program. A field study carried out by LBNL in 2002 with CEC funding demonstrated that sealing distribution systems saves substantial amounts of energy.

In 2005 and 2006, Vigilent (formerly Federspiel Controls) received CEC funding for projects that first demonstrated a combination of "smart" software and wireless temperature sensors and then supported further analytical R&D analyses. This work led to two CEC-funded demonstrations at UC Santa Barbara . The Vigilent system currently has 90 deployments and manages 23.2 MW of power. In 1996, with Massachusetts Strategic Envirotechnology Partnership (STEP) assistance, AIRxpert Systems demonstrated its technology at the University of Massachusetts Amherst. Since then, the technology has been implemented in many commercial buildings, including the Stratus Computer Company, Boston Museum of Science, New England Financial, a Federal building, MEC Corporation, three Boston schools, Brooks Automation, MIT's underground garage, and the Lawrence Convention Center in Pittsburg.

sMAP for Buildings was recently developed using National Science Foundation grants. A start-up company, Building Robotics, now provides support, installation, and development of building energy management and analysis systems based on this technology. It has been used by LBNL, Intel, the Center for the Built Environment, and the EECS department at UC Berkeley in the LEED Platinum David Brower Building, in Sutardja Dai Hall, Soda Hall, and Cory Hall on campus, and in the New York Times building. So far, it has been tested with Siemens Apogee and Johnson Controls Metasys BMS systems. There are no significant technical risks in this project, because all of the technologies already have been demonstrated separately. Our team has extensive experience developing and deploying these technologies and is very familiar with developing and implementing M&V principles, including developing models to represent air-handling system and whole-building energy and IEQ performance.

Many team members are world-class experts and industry leaders that have been involved in related technical areas for at least a decade. To address scalability and accelerate technology adoption, our team includes Schneider Electric, which is one of the world's largest Energy Service Companies (ESCO). They will lead our M&V and cost performance analysis efforts.

A significant related project is LBNL's current CEC-funded $2.8M project that is enhancing PG&E's UT tool, which focuses on air-handling system performance and M&V issues. Two other significant related efforts are LBNL's current $2.2M project "Optimizing Operational Efficiency: Integrating Energy Information Systems and Model-Based Diagnostics" and a $1.5M one that LBNL recently completed with United Technologies Research Center "Automated Continuous Commissioning of Commercial Buildings", both of which are funded by the U.S. Department of Defense. Potential overlaps with these and other projects that are about to or already have collected

relevant building performance data and developed building-specific performance models will be leveraged when possible to inform and support the proposed project.

Justification

The proposed project addresses “Building End Use Energy Efficiency”. In particular, it will reduce on site natural gas use and address technology gaps hindering the achievement of improved efficiency and reduced natural gas use in commercial buildings by a) advancing efficient technologies, design tools, and operations; b) demonstrating affordable, comfortable, energy efficient buildings; and c) maintaining or increasing productivity (based on IAQ) while reducing energy consumption and emissions.

More specifically, to accelerate adoption of retrofit technologies throughout California, the proposed demonstration will provide critical information in the form of performance quantification and screening/analysis tools. Quantifiable ratepayer benefits will be in the form of energy savings (which increase energy security), reduced costs (savings can offset costs of installing other retrofits or renewable energy sources), reduced green-house gas emissions, increased equipment reliability, and potentially improved IEQ for occupants. Based on past demonstrations, fan and cooling energy savings from system sealing alone could be in the range of about 10 to 60% and up to 40%, respectively and paybacks could range from 2 to 10 years, depending on the level of pre-retrofit leakage. The Vigilent technology has been shown to reduce typical cooling and heating energy costs from 20% to 40%, depending on facility type and use, and local utility rates. As an example, a 100,000 ft2 building could save approximately $70,000 per year in fan energy, with natural gas and chilled water savings contributing an additional $30,000. The system typically delivers a two-year return on investment. The AirXpert system, when implemented in a 250,000 ft2 building, saved 20,000 therms of natural gas and 300,000 kWh of electricity, equivalent to $45,000 annually with a payback of less than 18 months.

California-wide savings estimates at this time are crude because the extent of system deficiencies statewide and system interactions are not well characterized, but we expect the technologies to be broadly applicable. Assuming that 50% of the commercial buildings can be retrofitted (i.e., large commercial buildings) and that savings are 40% of HVAC energy, the statewide technical potential associated with this project is roughly 160 million therms and 8 TWh.

Ratepayer Benefit

x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

16. Longevity of Building Airtightness

Issues or Barriers

One-time testing of airtightness post-construction, or immediately following retrofit, only reflects the condition of the homes at that instant. However, the energy savings from reduced air infiltration might be overestimated if the building envelope or air sealing deteriorate over time. Programs or contractors do not re-test houses for airtightness because once the job is completed, there is little incentive to collect more data that might suggest that energy savings would be less than initially indicated. As a result, our current knowledge on the airtightness of homes is insufficient to predict the future residential energy needs for space heating.

Initiative Description and Purpose

Collect building envelope and duct system air leakage data again in homes that were tested before, e.g., <1, 3 to 5, and 10 or more years ago. Homes will be recruited from those that were tested when new, and built to the specifications of Title 24 airtightness guidelines that applied to homes when new. Homes will also be recruited from those that were retrofitted through weatherization and other energy efficiency programs, such as Energy Upgrade California. Blower door and duct blaster measurements will be conducted in roughly the same season as the previous test. Comparison with prior data will show if the building envelope and duct system of new homes built to Title 24 standards continue to perform as designed. The analysis will also identify risk factors where the retrofit measures failed to maintain airtightness over time. Building construction types, climate zones, home improvement or history of other renovations, etc., are all possible factors that may impact the longevity of building airtightness.

Stakeholders

This data will be useful to weatherization and other energy efficiency program managers and contractors by showing airtightness measures that perform well in the long run. This will promote building envelope and duct system airtightness in the California housing stock, and benefit homeowners in energy savings spent on space heating over time.

Background and the State-of-the-Art

Building envelope and duct system air leakage data have been gathered and analyzed since 1990s. Analysis shows that large variability in airtightness exists in housing stock. There is also a correlation between air leakage and year built, where older homes are far less airtight than newer homes. This suggests an opportunity where the airtightness in some homes may be worsening over time, perhaps due to construction practices that are particularly prone to deterioration in the building envelope and/or the duct systems. Moreover, a comparison of the airtightness of homes before and after retrofit by also found a large variability in improvement.

The data available to-date only support an overall estimate of the change in airtightness from retrofit projects, but there is insufficient data to compare the effectiveness and

longevity of these improvements. Preliminary analysis suggests that there are differences between the reduction in air leakage achieved by weatherization assistance programs and other residential energy efficiency programs, possibly because of the differences in how contractors approach these projects given the program requirements. The incentives available to homeowners may also influence the energy efficiency measures that are carried out.
Building envelope and duct system airtightness has a direct effect on the space heating energy usage in homes. Understanding their performance over the lifetime of homes will allow better predictions of the overall energy consumption. Such information can also be used to estimate at which time intervals should older homes be targeted again for airtightness testing and improvements.

Justification
About 40% of residential gas consumption is on space heating. This initiative will identify risk factors that lead to building envelope and duct system not maintaining airtightness over time both in new dwellings, and also in the existing homes when undergoing retrofits. The knowledge will be useful to contactors who can then apply best practices to achieve the most improvement in airtightness. This will benefit 20,000+ new single-family homes being built in California annually in recent years, and also the 10,000+ homes being retrofitted through weatherization annual program funding (i.e., excluding ARRA) and other residential energy efficiency programs.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
  GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative

17. Low-energy residential hybrid ventilation with filtered supply air

Issues or Barriers

California will require new construction residential buildings to be zero net energy by 20201. This will require tight building envelopes, thus necessitating managed ventilation systems in order to maintain indoor air quality (IAQ) and meet ASHRAE Standard 62.2 (adopted by Title 24). In California, space heating accounts for 44% of residential gas consumption. Approximately 30% of the space-heating load is from increased air exchange due to ventilation.

The RESAVE project for the CEC (http://resave.lbl.gov) has shown that hybrid ventilation systems can reduce residential ventilation-related energy loads by 24%, when compared to continuous mechanical exhaust systems. This reduction in energy (and gas use) can be achieved while providing IAQ equivalent to ASHRAE 62.2.

PM2.5 (fine particles less than 2.5 micrometers in diameter) has been identified as a major contaminant of concern for the indoor environment, and filtering outdoor air to remove PM2.5 will substantially improve IAQ from a health perspective. The outdoor concentration of PM2.5 has been shown to be timedependent due to variable emission rates from traffic and the diurnal variation in the atmospheric boundary layer. The inability for hybrid and natural ventilation systems to filter outdoor air is a barrier to their wide-scale adoption, despite their energy benefits.

Initiative Description and Purpose

A research company proposes the development of a residential hybrid ventilation system that combines passive stack ventilation, RIVEC, and a filtered mechanical supply fan. This initiative builds from the PIER-funded RESAVE project that demonstrated the value of both residential hybrid ventilation and RIVEC - the Residential Integrated Ventilation Controller. An appropriately sized passive stack with flow-limiting controls provides the majority of the household ventilation. At times of low natural driving forces and/or high outdoor PM2.5 concentrations the filtered supply fan provides 100% of the outdoor ventilation to reduce the IAQ impact of particles. RIVEC is integrated into the hybrid system and used to coordinate the use of the supply fan with other systems in the house that provide ventilation, such as bathroom exhausts and kitchen extract fans. This approach prevents over-ventilation and minimizes the spaceheating load and gas consumption. Reducing the gas burned in residential furnaces will also reduce the localized concentration of outdoor exhaust particles. RIVEC is also designed to shift up to 100% of ventilation-related energy use during peak power demand periods to off-peak times. This helps reduce the demand for the construction and operation of expensive ‘peaker’ power plants and smooths the time-dependency of California’s gas and electricity demand.

The project will have two components:

1) Computer simulations will be performed as a proof of concept. The project will use REGCAP – LBNL's in-house residential building energy simulation tool. The energy and IAQ performance of the hybrid ventilation system will be modeled, and its suitability assessed, in different houses and in different California climates.
2) A prototype system will be designed, constructed and tested using the climatic chamber facility at LBNL. The suitability of existing commercially available components to be incorporated in the system will be assessed. These components include mechanical airflow controllers that prevent over-ventilation in the passive stack, sensors/indicators for outdoor PM2.5 levels, and sensors to relay the airflow in the passive stack to RIVEC. RIVEC hardware and firmware will be updated to allow its incorporation into the hybrid system. If proof of concept and system prototyping phases are successful then a subsequent field-testing phase of the project shall be necessary before the system can be developed for market.

Stakeholders
CEC/Title 24, Home Ventilating Industry, Panasonic

Background and the State-of-the-Art
The hybrid system was first proposed by Turner and Walker3, albeit using a RIVEC-controlled exhaust fan rather than a filtered supply fan. The system is currently at a proof of concept stage. RIVEC is a proven concept and has been the subject of both computer simulation work3 and the field-testing of a prototype system9 for the CEC and the DOE. Computer simulations have shown that RIVEC can reduce ventilation – related loads associated with whole-house ventilation systems by 40%. Field-testing showed that RIVEC provided equivalent IAQ to a continuously operating mechanical system while reducing mechanical fan operating time from 100% to 45%.

Justification
The hybrid ventilation system could potentially remove 11% of California's residential gas demand, and eliminate up to 100% of ventilation-related gas consumption during peak periods, while reducing indoor concentrations of PM2.5 due to ventilation. The project will also extend the market scope of RIVEC by allowing its incorporation into hybrid ventilation systems.

Ratepayer Benefit
Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative:

18. Monitoring air pollutants from natural gas combustion appliances in residential buildings.

Issues or Barriers

Air sealing of homes to reduce the uncontrolled entry of outdoor air is typically among the most cost-effective retrofit measures to reduce energy consumption and associated greenhouse gas emissions. However, tighter (better sealed) houses present potential health hazards to occupants because they depressurize more readily when using exhaust fans, including bathroom fans, range hoods, and dryers. Depressurization increases the likelihood that the ordinary, upward exhaust flow of vented combustion appliances—such as water heaters and furnaces—will be reversed in a process called "backdrafting." Backdrafting can cause combustion exhaust products to spill into the home rather than being vented upward and out through the vent. This spillage can expose residents to hazardous air pollutants that are produced by the combustion appliance burners. Existing short-term combustion safety diagnostic used to identify problematic appliances are time consuming, expensive and do not reliably predict performance of combustion appliances. In June 2012, DOE's Building America Program and the Partnership for Advanced Residential Retrofit (PARR) hosted an expert meeting on combustion safety, to identify gaps and barriers in the research and progress toward harmonization of existing combustion safety protocols. During this meeting, combustion safety experts recognized a deficiency of indoor pollutant data associated with spillage. Until more long-term monitoring data of indoor air pollutants becomes available, the risk mitigation associated with spillage cannot be fully assessed, preventing air sealing of homes.

Initiative Description and Purpose

The purpose of this initiative is to assess the risk associated with combustion appliances by monitoring indoor pollutants (such as carbon monoxide, oxides of nitrogen, and particulate matter) over the course of 1-2 years in 1,000 California homes. Collection of long-term data on this magnitude does not exist and would be invaluable to the energy upgrade retrofit community nationwide. Data collected from this initiative could be used to improve the use of simulation software to predict combustion appliance venting (i.e. VENT-II) and indoor air quality (i.e. CONTAM) when tightening homes. Most importantly, this data would validate concerns associated with air tightening and combustion appliance backdrafting and could be used to improve reliability and reduce cost of existing combustion appliance safety diagnostics while mitigating risk.

Stakeholders

Low income weatherization programs (i.e. Building America) California utilities National laboratories and other research institutions AGA Energy Auditors (i.e. BPI and RESNET) CEC/Title 24

Background and the State-of-the-Art

A substantial amount of research has been conducted to assess combustion appliance backdrafting and spillage test methods. The research generally concludes that many short-term combustion safety diagnostics should be interpreted with caution, as they tend to over predict the number of spillage prone houses and results vary significantly with outdoor conditions.

Results from monitoring in homes that failed the short-term diagnostics found that events of sustained spillage were extremely rare. However, the one-week duration of monitoring that occurred in most of the published studies is too short to reliably conclude that the studied appliances and houses will not have any incidences of spillage over the course of a typical year.

Extensive monitoring has not been conducted in houses that pass short-term combustion safety diagnostics. The reliability of such tests to identify all houses that are at risk is therefore unresolved. Additionally, most of the research has been conducted on homes dissimilar to California homes. Currently, a PIER Buildings project is funding Lawrence Berkeley National Laboratory (LBNL) to develop a diagnostic protocol. The goal of this project is to improve understanding of backdrafting and spillage of combustion products from natural gas appliances in California homes that have been or will be retrofitted for air-tightness. This information will support development of a more robust and consistent diagnostic protocol to enable maximum air sealing for energy efficiency without creating spillage-related indoor air quality hazards. A DOE funded project, also being conducted by LBNL, focuses on monitoring to determine the frequency of backdrafting and spillage in homes having risk factors for improper venting of natural draft appliances. This project will provide initial monitoring data for improving combustion safety as only 50 California homes will be monitored. In order to validate existing combustion safety protocols and mitigate risk, more monitoring is needed.

Justification

Diagnostic procedures for combustion safety are time consuming and do not reliably predict performance. The related cost and uncertainty of such procedures has kept many current programs from pursing aggressive air tightening. Additionally, these diagnostics procedures do not take into account risk mitigation associated with spillage. Lack of long-term indoor air quality data from residential buildings is preventing air sealing of homes because the health risk associated with spillage from combustion appliances and the frequency of spillage cannot be assessed. Monitoring indoor air pollutants in 1,000 California homes for a 1-2 year period would provide natural gas ratepayer benefits by:

- Assessing the health risk associated with major pollutants from combustion appliances over a range of weather conditions.
- Developing a reliable, onsite combustion safety diagnostic that mitigates risk and allows for aggressive air tightening of residential buildings.
- Developing and improving simulation software used to predict venting of combustion appliances.
- Reducing cost and improving reliability when performing residential energy upgrades.

Ratepayer Benefit

x Promote greater reliability
  Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative

19. Optimizing Heat Recovery In CA Homes

Issues or Barriers

Heat recovery ventilators (HRVs) is a machine that ventilates a home while recovering a large fraction of the heat that would otherwise be lost when using a simple exhaust fan. HRVs are currently not suggested in California homes because the energy savings for whole house ventilation are thought to be less than the additional energy and installation costs of an HRV versus a standard exhaust fan. HRVs aligned with range hood exhaust have the potential to be cost effective, however concerns about cooking exhaust fouling the HRV and data on the heat capture efficiency of range hoods are a barrier to using HRVs in this mode.

Initiative Description and Purpose

The purpose of this initiative is to determine if HRVs would be cost effective in CA if put in line with kitchen range hoods and to develop the technology needed to use HRVs in line with cooking exhaust. The initiative would have measurement, modeling, and design components. The more resource intensive part of the work would be to determine, for a representative subset of the US residential range hood stock, range hood heat capture efficiency. Less resource intensive would be the modeling and economic analysis to determine the costs and benefits of HRV use in conjunction with range hoods on the CA housing stock and, if HRVs are shown to be cost effective, research to develop the technology needed to effectively operate HRVs in line with cooking exhaust without system fouling.

Stakeholders

The California Energy Commission and individual home owners are stakeholders because this technology will reduce home energy use and GHG emissions. The HRV industry is also a stakeholder because the developed technology may increase their market size in CA substantially.

Background and the State-of-the-Art

Research at the Lawrence Berkeley National Lab has shown that range hood use during cooking is necessary to provide good indoor air quality. Modeling of cooking behavior has indicated cooking in an average CA produced 100 kWh annually (high cooking homes produced over 3,000 kWh annually) [1]. When range hood use is introduced into the home, some fraction of the cooking energy that had previously entered the space is exhausted. In the winter, the exhausted heat will have to be replaced by the central heating system to maintain thermal comfort resulting in a net increase in annual heating energy. The energy penalty will be even larger in homes with low efficiency heating systems and leaky ducts such as forced air systems. Recovering the cooking heat energy could result in significant reduction in the additional annual heating costs due to range hood use. Currently, modeling the energy impact of range hood use is impaired by the lack of available data on heat capture efficiency of hoods.

This data would allow for the determination of the cost benefit ratio of HRV use in line with range hoods. If the approach is cost effective, than technology would need to be developed to allow for the use of HRVs in line with cooking exhaust such as ways to manage grease emissions from cooking to avoid fouling the HRV.

Justification

Range hood use during cooking is necessary to maintain good indoor air quality. Range hood use in CA has the potential to increase rate payer costs for natural gas heating by $150-400 annually in homes with a high level of cooking [2]. Effective HRV use could reduce that cost by over 80%. The potential market for this technology would be the CA housing stock that uses heating. According to the Residential Appliance Saturation Survey, 93% of CA residents have heating and could derive some benefit from HRVs in range hoods, however the benefits will likely only out weight the costs in the colder climates of CA. We estimate that the development of HRVs that can be used in conjunctions with range hood could impact 25-50% of the CA housing market.

Ratepayer Benefit

Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative

20. Developing probabilistic future weather files for the CA housing Stock

Issues or Barriers

Currently energy modeling is extensively used to determine the energy impact of building technologies and energy efficiency upgrades. The modeling relies on weather files that are based on historical weather data. Climate change has been predicted to impact both the mean and variability of future weather patterns throughout CA. The building stock changes relatively slowly, indicating that there is a need to build and refurbish buildings now with the implications of climate change in mind. To do this requires probabilistic future weather files to reflect the predicted changes in weather in the 16 climate CA Title 24 climate zones. Currently weather typical weather files that are used are for an average year and do not include extreme events. As extreme events become more common place, weather files are also needed to explore the impact of extreme events on building energy use and peak demand.

Initiative Description and Purpose

The purpose of this work is to explore the feasibility of developing and to develop weather files that reflect the impact of global climate change on future weather patterns throughout CA. The developed weather patterns would look at the impact of both changes in average weather patterns and in the variability of weather patterns such as the increased likelihood of extreme events. The impact of these changing weather patterns on projected building energy performance will be explored as well as the impact on aggregate energy demand. US peaking plants are typically natural gas. Increases in extreme weather will increase the peak demand and could strongly impact natural gas use patterns and infrastructure.

This work will require a partnership between building energy modelers and climate science modelers. As part of the International Panel on Climate Change work, extensive modeling has been done on a global scale to determine regional impacts of climate change due to a variety of proposed scenarios. Regional scale weather research and forecasting modeling tools, such as WRF-CHEM, can be used to determine the impact of large regional changes on local weather patterns for each of the proposed scenarios. The impact on building energy predictions using the developed weather files will be compared to currently used TMY3 weather in building energy simulation models such as REGCAP and EnergyPlus. The results can be used to determine if these changes in weather files will have a significant impact on building energy predictions for Title 24 compliance building modeling. The outcome will be a methodology for including climate change in predicted energy use models as well as an assessment of the impact of future climate changes on building energy use.

Stakeholders

The main stakeholder is the California Energy Commission and individual home owners as weather will impact the energy savings of proposed building changes and new building designs. Weather will also impact future natural gas demand in CA.

Background and the State-of-the-Art
There is overwhelming evidence that the climate is changing global weather patterns. The International Panel on Climate Change estimated that the average global surface temperature will increase by up to 7°C from 1990 levels by the end of the 21st century. The occupancy trend in California is to move towards more urban living, indicating that the urban heat island effect, higher mean temperatures in cities than in surrounding areas, will also impact building energy use. The buildings we build today in CA need to be energy efficient in future climate scenarios. Simulation packages for predicting building performance will require weather data files that reflect changes in future weather patterns. This need has already been recognized in the UK where sizeable resources have been devoted to assess the future impact of weather on predicted building energy use[1]. Moving toward net zero energy buildings, a major goal in CA, requires buildings that are designed for the environment they will occupy in the future.

Justification
The California Energy Commission currently relies heavily on modeling tools for assessing Title 24 compliance and for predicting the energy savings of proposed changes to the building stock. If the weather files used are not reflective of actual future weather scenarios then predicted energy savings could be significantly different then actual savings resulting in incorrect decision making about how buildings should be constructed or retrofitted to reach energy reduction goals in CA.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
  GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative:

21. Technology Advancements in Gas-fired Commercial Food Service Equipment

Issues or Barriers

1) Reduction of Criteria Pollutants: The vast majority of gas-fired commercial cooking equipment utilizes old atmospheric burner technology which emits relatively high levels of nitrogen oxides (NOx). New improved lower polluting burner systems, which have been developed for other applications like water heating, space heating and small boilers, could be applied on various types of commercial food service equipment.

2) Increase in Cooking Efficiency: In recent years, industry and the CEC have funded the development of higher efficiency commercial cooking equipment on a few of the higher sales volume equipment types such as fryers and ovens. However, this past work only addresses a small minority of equipment. Additional investment is needed to continue the development of other high efficiency cooking equipment.

3) Further Development of Testing Protocols / Equipment Validation to Voluntary Standards: Commercial cooking equipment has long suffered from a lack of standardized methods to validate cooking performance and efficiency. Equipment manufacturers commonly quote product efficiencies based on their own in-house testing methods which can vary significantly without set testing protocols. The Food Service Technology Center in San Ramon, California has led an effort to establish test protocols for food service equipment types for qualification to rebate incentive funding offered under the California Energy Star program. Additional funding is needed to further protocol development for other equipment types that do not have established Energy Star categories. In addition, funding is needed to establish baseline efficiency data for all commercial food service equipment categories

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Initiative Description and Purpose

The primary objectives of this work is to modernize commercial food service equipment by making significant improvements in cooking efficiency, improvements in the emissions profile and through establishment of standardized testing protocols for equipment qualification for Energy Star rebate programs.

Stakeholders

Commercial food service operators will benefit from the use of higher efficiency cooking equipment by lowering their monthly energy bills.

Development and use of lower polluting gas-fired equipment benefits all Californians through improved air quality.

Food service operators will benefit from validated testing of cooking equipment to standardized protocols and for qualification of equipment for the California Energy Star program. This would allow improved decision making when purchasing a new piece of cooking equipment, providing a true apples to apples comparison of competing products.

Background and the State-of-the-Art

1) Reduction of Criteria Pollutants: There has been little if any development work conducted to reduce NOx emissions from commercial food service equipment. So far, local California air districts have not pursued NOx emission regulations for this category of gas-fired equipment. However, due to extreme air quality issues in southern California, it is reasonable to anticipate future regulations in SCAQMD and SJVAPCD will include significant reductions of NOx for this equipment type.

2) Increase in Cooking Efficiency: Overall, the efficiency of commercial food service equipment has not changed much in the last 30 years. The Energy Star program in California, which provides incentives to operators to purchase qualifying high efficiency equipment, has helped to push manufacturers to develop and commercialize equipment with improved efficiency. Currently there is an ongoing project funded by CEC and UTD to develop a high efficiency wok, conveyor oven, convection oven and range.

3) Further Development of Testing Protocols / Equipment Validation: The Food Service Technology Center in San Ramon, California has led an effort to establish test protocols for food service equipment types for qualification to rebate incentive funding offered under the California Energy Star program. Additional funding is needed to establish baseline efficiency data for all categories of commercial food service equipment and to expand on the ongoing work to establish testing protocols for the Energy Star program.

Justification

There are an estimated 960,000 commercial foodservice operations in the United States with annual sales around $604 billion. Nationally, this market segment employs about 12.8 million people. According to a CEC PIER report conducted by FSTC, there are about 93,300 commercial food service operations in California. This report estimated that there are about 795,000 pieces of food service equipment with about 70% being gas-fired and 30% electric. Estimated gas consumption for the California market is 475 MM therms annually. Total annual gas sales to the commercial foodservice market in SoCalGas serving territory are approximately 205 MM therms.

Historically, the primary drivers for purchase of commercial food service equipment ar first cost, equipment reliability, food production (volume), and food quality. Low energy prices have made operating costs (efficiency of equipment) to be of secondary importance. Environmental concerns have also not been of primary concern for operators or equipment manufacturers. These factors have produced an inventory of existing equipment that is not very advanced with overall mediocre efficiencies and relatively high emission profiles. Air quality regulations will likely mandate the production and use of cleaner burning equipment. Manufacturers will need to do a better job of justifying the incremental cost of higher efficiency equipment. Utilities can assist with this by continuing to promote rebate programs and by providing tools to operators that help demonstrate reasonable pay back on investments for advanced equipment.

Ratepayer Benefit

x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative:

22. Lower Cost Condensing Water Heater

Issues or Barriers
Current product offerings for high-efficiency condensing gas water heaters have thermal efficiency over 90%, and come with a significant cost adder over non-condensing water heaters. Costs for these products are increasing as water heater burners are being replaced with more expensive burners in order to meet 14 ng NOx/J output (SCAQMD NOx emission requirements). A primary area of opportunity for cost reduction is in lower cost, more efficient condensing heat exchanger designs and utilization of less expensive low NOx burner technology.

Description and Purpose
The primary purpose of this work would be to reduce the first cost premium of condensing water heaters in comparison to standard non-condensing tank type water heaters, providing operators an attractive, acceptable payback period.

Stakeholders
Residential and commercial operators of water heating equipment will benefit from commercialization and use of lower cost condensing water heaters. In addition, manufacturers of water heating equipment will benefit from selling more competitively priced high end products. Society will benefit from reduced fuel use and corresponding reductions in greenhouse gas and criteria pollutants, contributing to a cleaner environment.

Background and the State-of-the-Art
According to AHRI shipment data, there are 100,000 gas-fired commercial water heaters shipped a year. Low- to mid-size (100 kBtu/hr < Qin < 500 kBtu/hr) capacity condensing systems are priced from $5,000 to $15,000. In SoCalGas territory there are approximately 65,000 core commercial water heating units and 23,000 small hot water supply boilers that consume approximately 230 MM therms per year. On the residential side, there are approximately 2.4 million water heaters that consume about 950 MM therms annually.

Justification
Benefits of this work will accrue to the gas industry and its customers. The gas industry will benefit by being able to provide advanced high efficiency and reliable gas-fired equipment options. Consumers will benefit from more cost-effective, reliable and durable gas products. Identifying and resolving water heating technology and market issues will help the gas industry maintain viable gas water heating options in the future that meet customer expectations for cost, safety, reliability, and performance while complying with the letter and intent of current and future regulations.
GTI has conducted research over the last several years looking at various issues with residential and commercial water heating including completion of a baseline study of

residential water heating and the impact of water quality on water heater efficiency. GTI has also conducted some work looking at cost reduction strategies of condensing water heating products.

Ratepayer Benefit

x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative:

23. Gas engine-driven heat pump and absorption system packages

Issues or Barriers
Natural gas engine-driven heat pump and absorption technologies are not cost effective when compared to conventional electric and/or combination systems. While natural gas is a clean burning fuel, cost barriers to greater adoption of these technologies include material costs, exhaust gas treatment, maintenance costs and a lack of maintenance support.

Initiative Description and Purpose
Advancement in combustion gas engine-driven heat pump and absorption technologies would allow for greater adoption of very energy efficient natural gas driven HVAC systems. More research and development are needed to help drive down the overall costs of these systems while also meeting all California emission standards. Also, absorption and heat pump technologies could also be fired by unconventional means such as from waste heat streams and/or renewable solar thermal arrays with gas back up in a hybrid configuration.

Stakeholders
DOE, CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Engine driven, absorption and engine driven heat pumps already exist in the market but have not been well adopted in California. Current technologies achieve COP's from 1.3 to 1.6 for heating and 0.7 to 1.2 for cooling. However, these machines either do not meet California emission requirements for NOx or are too expensive to compete with conventional heater and air conditioner in both residential and commercial markets.

Justification
• Energy Efficiency
• Greenhouse gas reduction
• Broad application of the technology
• Electricity peak load reduction

Ratepayer Benefit
x Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost

Name of Initiative:

24. Heat Pumps

Issues or Barriers
Absorption and engine driven heat pumps already exist in the market but have not been well adopted in California due to high cost, emissions and a lack of public awareness of the energy efficient capabilities of heat pumps, and because there is very little service support for the equipment available. Heat pumps can be directly gas fired or by some form of heat recovery like waste heat or a solar thermal array.

Initiative Description and Purpose
Develop high efficiency heat pumps that can and will be supported by the manufacturer in the field, which is a function of market share. Provide for the development of new refrigerants that allow for a reduction in heat exchanger material costs. Facilitate unconventional applications of heat pumps, like with recovered heat sources and/or solar thermal heat sources. Essentially, equipment cost reductions are needed.

Stakeholders
DOE, CARB, SCAQMD, SCG

Background and the State-of-the-Art
Current technologies exist and achieve COP's from 1.3 to 1.6 for heating and 0.7 to 1.2 for cooling. However, these machines either do not meet California emission requirements for NOx or are too expensive to compete with conventional heaters and air conditioners in both residential and commercial markets.

Justification
• Energy Efficiency
• Greenhouse gas reduction
• Broad application of the technology
• Electricity peak load reduction

Ratepayer Benefit
x Lower operating costs
x GHG emissions mitigation at the lowest possible cost
x Efficient energy use

Name of Initiative:

25. Small Residential Fuel Cells in Co-generation Applications

Issues or Barriers
Fuel Cells offer the advantages of high electrical efficiency, high quality power, small footprint, low emissions, and the opportunity for co-generation using the waste heat produced by the unit. They are being commercialized in Southern California but at a low rate. The waste heat is typically used to heat swimming pools or domestic hot water. Prices will continue to decline as more units are placed in the field. One way to accelerate this process is to demonstrate new co-generation applications. A high temperature Proton Exchange Membrane (PEM) fuel cell could be coupled with an absorption chiller or other thermal refrigeration cycles to provide both electricity and cooling to the residential
customer.

Initiative Description and Purpose
Develop and demonstrate a co-generation fuel cell system (3 – 5kW) which would support residential air-conditioning through the use of the heat derived from the fuel cell. The project could be conducted in two parts. The first would be development and testing of the system by the fuel cell manufacturer. The second phase would be the installation and demonstration at a SCG customer site.

Stakeholders
DOE, SCAQMD, SCG, Industry Partners

Background and the State-of-the-Art
Current small fuel cell technologies offer electrical efficiencies approaching 40%. Existing home cooling systems are available that can be powered by either electricity or natural gas. There is no current system available to the consumer that will both generate electricity and provide cooling. The payback to the consumer for current fuel cell systems is in excess of 5 years. Utilizing the waste heat to provide cooling to the customer could reduce this time significantly.

Justification
EIA estimates that in 2010 about 479 billion kilowatt- hours of electricity were used for cooling by residential and commercial sectors, representing about 12% of total U.S. electricity consumption. Of that, about 316 billion kWh was used for cooling by the residential sector, which was about 22% of the total residential electricity consumption. Using small fuel cells to off-set some of this load would provide the benefits of onsite power generation – high electrical efficiency, low emissions, no transmission losses, etc. with the opportunity to provide cooling to the customer at no additional operating cost.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

26. MicroCHP

Issues or Barriers
Existing MicroCHP technologies deployed in California are limited to fuel cells, which remain cost prohibitive for wide deployment. Fuel cell and engine technologies are matured and widely adopted in a large scale. Small residential scale systems (1kW-5kW) are experiencing technology challenges, stringent emission, and high cost that would make it cost effective. Internal combustion engine driven systems, available in US markets and there may be some Stirling engine systems, and organic Rankine cycle systems coming to US markets but none of these systems are capable of meeting CARB air quality standards. In addition, most of these technologies work best when utilized as both a generator and water heater, so despite being designed for residential applications, they are best suited for small commercial applications that utilize large volumes of hot water.

Initiative Description and Purpose
Development of affordable MicroCHP technologies that meet CARB standards, provide efficient use of energy and thus can be deployed on a large scale to residential and/or small commercial markets in California.

Stakeholders
DOE, CARB, SCAQMD, SCG

Background and the State-of-the-Art
MicroCHP systems are widely adopted in Europe and Japan in residential and light commercial installations. Utilities in these countries heavily subsidize these installations due to its environmental, peak demand, and energy efficiency benefits. Only fuel cell technologies meet CARB emission standards at present and the systems that do remain too cost prohibitive to be deployed with any consistency. Internal combustion engine systems are available at much better price points but they do not meet CARB emission standards. Both technologies offer overall energy use efficiencies in excess of 80%.

Justification
• Energy Efficiency
• Greenhouse gas reductions
• Electricity load reduction at all times
• Net Zero Energy potential

Ratepayer Benefit
x Promote greater reliability
x Lower costs
Increased safety

x Societal benefits
x GHG emissions mitigation at the lowest possible cost

Natural Gas – Proposed Research Initiative

Program Area:

Industrial, Agriculture and Water Sector End Use Efficiency.

Reduce energy use and cost in the industrial, agriculture and water sectors through development of advanced technologies and processes that reduce energy use and costs, increase energy efficiency and maintain or increase productivity while reducing emissions. Examples include: process improvements; heat recovery from combustion systems and natural gas burners; water/wastewater treatment process improvements; irrigation sensor and control improvements; indoor air quality; and other types of research associated with this sector.

Name of initiative:

27. Solar Thermal Process Steam

Issues or Barriers
Many of the agricultural processing companies in the State of California have significant thermal loads distinct from relatively low temperature hot water. These loads are typically for cooking, sterilizing, pasteurizing and drying. Some of the target industries would be dairy products, wine and beer production, and vegetable processing. The intense solar radiation in southern California makes it an ideal location for the generation of process heat from solar energy. The barriers to implementation include the low cost of natural gas, the availability of vacant land adjacent to an existing facility, and the high cost of solar thermal systems that operate at the high temperatures needed by these industries.

Initiative Description and Purpose
A research company has developed a low cost solar thermal system capable of >30% optical efficiency and >300^{o} C (>572^{o} F) heat. Thermal oil is used as the heat transfer medium that can be used directly or as a heat source to produce steam. The solar thermal energy used during the daylight hours, when most work is done, reduces atmospheric emissions.

Stakeholders
CARB, SCAQMD, SoCalGas, other industry partners.

Background and the State-of-the-Art
Solar thermal power generation has focused on large facilities and exclusively electrical power production. Combined Power has focused on small-scale solar thermal built from low cost materials. Their Hyperlight® system has been demonstrated at full-scale geometry in a one-quarter size installation. Combined Power has broken ground on its first full-size commercial-scale installation in Brawley, California.

Justification
- Energy Efficiency
- Greenhouse gas reduction
- Particulate airborne emission reductions
-

Ratepayer Benefit
x Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost

Name of Initiative:

28. Research natural Gas Engine technologies to produce natural gas engines at lower costs for the agriculture industry

Issues or Barriers
Barriers to full market adaptation is the cost of natural gas engines. In the past lack of information was a factor as well but right now the cost of the natural gas engine needs to be decent for businesses and fleets to purchase them.

Initiative Description and Purpose
The technology will allow the natural gas engines to be produced at lower costs and will address one of the biggest issues.

Stakeholders
Business, fleet operators, agriculture businesses, farms, natural gas engine manufacturers, CNG component manufacturers and the general public since the fuel cost is almost half the cost of Gasoline or diesel. All these entities support the initiative.

Background and the State-of-the-Art
Currently there are very few natural gas engine manufacturers in the USA maybe one or two. They do produce engines however the cost is very high and it makes the overall purchase of a natural gas engine very expensive. There is research going on in this field however nothing has really been done to lower the cost of producing these engines. The technologies are in the proof of concept stage and need to go further to see what can be done. There hasn't been anything done in the industry yet to lower the cost of producing these natural gas engines. There are many incentives in California for funding alternative fuel but not enough for natural gas technologies or engines. Natural gas is abundantly available in the US and using will help reduce our dependence on foreign oil. Electric is also considered an alternative fuel however electric is still not viable as the cost of batteries is high and range issues, and long charging time still need research and there is till a lot of work needed to overcome these issues.

Justification
This technology will provide natural gas ratepayers benefit since they can purchase an engine at a lower cost than what is available now.
• Sector sizes can vary with fleets, farmers, businesses and transportation delivery businesses. There are companies who use up to 1 billion dollars worth of diesel fuel in running diesel engines and vehicles imagine if that can be cut by half if by the fleets being able to use natural gas fuel.
• The technology can be used within the engine manufacturer industry
• Maximum market potential is huge, the market needs a lower priced natural gas engine.

Ratepayer Benefit

x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
  GHG emissions mitigation at the lowest possible cost
  Economic development

Name of Initiative:

29. Heat Transfer Improvements

Issues or Barriers
Differences in heat transfer modes, large variety in equipment designs and process conditions, costs.

Initiative Description and Purpose
Develop and demonstrate technologies that can significantly increase overall heat transfer rates in a variety of natural-gas utilization applications over a wide range of process conditions. Promote collaboration between R&D community, suppliers and users for effective technology transfer.

Stakeholders
Industrial and commercial energy users, equipment suppliers and installers; R&D organizations, including universities and natural gas utilities.

Background and the State-of-the-Art
A wide range of techniques are used to improve heat transfer rates in residential, commercial and industrial equipment. These include surface enhancements, increased turbulence, controlled velocities, use of higher heat transfer materials/ cladding, increasing flame radiation/convection, and increasing radiant surfaces, using high emissivity refractories/coatings. These techniques improve heat transfer rates to a varying degree, however, opportunities exist for large improvements which can reduce equipment size and costs, increase equipment life, increase efficiency of heat transfer and supporting equipment, and reduce air pollution.

Justification
Most of the natural gas fired equipment used across market sectors uses some form of heat transfer. Heat transfer improvement technologies that cut across modes, applications and process conditions can have significant impacts on efficiency, economic and environmental impacts across the natural gas market chain.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

30. Waste Water Recovery Using Process Waste Heat

Issues or Barriers
High capital and maintenance costs, corrosion and fouling of heat and water extraction equipment, low effectiveness of particulate/ vapor removal, recovery system heat losses and complexity, ineffective collaboration between R&D community, users and suppliers.

Initiative Description and Purpose
Develop and demonstrate reliable, cost effective and simpler technologies for recovering usable water from dirty process water from exhaust gases using available process waste heat.

Stakeholders
Industrial natural gas users, equipment suppliers, installers and commissioning agents; R&D organizations including universities and natural gas and water utilities.

Background and the State-of-the-Art
Hot gas filtration coupled with complex and expensive recovery system designs that do not effectively address the key issues and barriers identified.

Justification
Availability of clean process water and cost of dirty water disposal are becoming more important concerns. Processes to use available waste heat on site to recovery clean water from dirty water streams or to recover water from exhaust gases at reasonable costs are receiving more attention. There is opportunity for simultaneous recovery of large amounts of heat and water if cost effective, simpler, higher efficiency and reliable technology can be developed.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

31. High Efficiency Drying

Issues or Barriers
High capital costs, low equipment efficiencies, inadequate quality of drying, pollutants Deterioration of product in direct fired dryers, dryer temperature limits and efficiency in steam drying. Ineffective collaboration between R&D community, users and suppliers

Initiative Description and Purpose
Develop and demonstrate compact, high efficiency direct and indirect industrial dryer concepts that can achieve over 80% thermal efficiency. Promote collaboration between R&D community, suppliers and users for effective technology development and commercialization.

Stakeholders
Agriculture producers, food products and paper manufacturers, their equipment suppliers and installers; R&D organizations, including universities and natural gas utilities and ratepayers.

Background and the State-of-the-Art
A number of technologies, both direct and indirect fired, are available for material drying. Large improvements in drying process efficiency and process costs are still possible. Significant opportunities exist for technological improvements to lower costs, increase efficiency and improve product quality.

Justification
Industrial dryers consume over many millions of Btus of energy. Even a small increase in efficiency can result in large energy savings and GHG reductions.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost x
x Economic development

Name of Initiative:

32. High Temperature Waste Heat Recovery

Issues or Barriers
High capital and maintenance costs, high material costs, large footprint, equipment complexity, corrosion and fouling of heat extraction equipment, ineffective collaboration between R&D community, users and suppliers. Increased NOx emissions.

Initiative Description and Purpose
Develop and demonstrate compact and lower cost heat recovery technology that minimizes fouling and corrosion and NOx emissions and effectively transfer the technology to the market.

Stakeholders
Industrial natural gas users, equipment suppliers, installers and commissioning agents; R&D organizations including universities and natural gas utilities.

Background and the State-of-the-Art
A number of technologies have been developed to recover high temperature waste heat. Most of these transfer the recovered heat to the combustion air, which increases flame temperatures and NOx generation. Other methods convert the waste heat into power by using steam/organic Rankin cycles and other thermodynamic cycles, however these techniques are expensive and complex.

Justification
High temperature waste heat from the industrial sector offers a significant opportunity for improving the performance and economics compared to the current state of the art technologies.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative

33. Low Level Waste Heat Recovery

Issues or Barriers
High equipment costs; ineffective extraction of low level heat e.g. size, corrosion and fouling; low efficiency of recovery; lack of documented field data proving system reliability, safety and economics; uncertain fuel prices and insufficient coordination between R&D community, suppliers and users for effective technology transfer. Key technical issues are size, corrosion and fouling of energy extraction equipment.

Initiative Description and Purpose
Develop effective compact, reliable and low cost heat recovery technology, conduct high visibility demonstration and document results.

Stakeholders
Industrial manufacturers; equipment suppliers, installers and commissioning agents; R&D organizations including universities; natural gas utilities and DOE.

Background and the State-of-the-Art
A wide range of heat exchanger designs for heat extraction and energy conversion techniques have been deployed and evaluated, however, the barriers and issues identified remain.

Justification
Low level waste heat (< 450ºF) from the manufacturing industry amounts to 1 to 2 QBtu of energy annually in the US, representing a large opportunity for energy savings, GHG emissions reduction and economic activity.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

34. Near Zero NOx Combustion Systems

Issues or Barriers
Adverse impacts on combustion stability, other pollutant emissions, thermal efficiency, costs and application flexibility.

Initiative Description and Purpose
Develop and demonstrate combustion concepts that achieve Near Zero NOx generation in a wide range of low to medium temperature (< 1500ºF) applications without adverse impacts on combustion stability, other pollutant emissions, thermal efficiency and costs.

Stakeholders
Industrial, commercial and residential energy users, equipment suppliers and installers; R&D organizations, including universities and natural gas utilities.

Background and the State-of-the-Art
Fuel and air staging and high excess air, both coupled with improved fuel-air mixing are the most common techniques researched/developed to reduce NOx emissions to single digits. These techniques however result in combustion instabilities, elevated emissions of CO/unburned hydrocarbons and, when using high excess air, a significant reduction in thermal efficiency and increase in equipment size and air blower power requirements. Post combustion techniques are expensive, complex and can result in ammonia slip.

Justification
Increasingly strict NOx emissions regulations require development and deployment of cost effective, safe and reliable combustion techniques that can limit NOx generation to Near Zero levels.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

35. Oxygen-Enriched Combustion

Issues or Barriers
Low efficiencies, high NOx emission levels and large footprint of industrial processes. High costs of converting to relatively pure oxygen.

Initiative Description and Purpose
Develop and demonstrate techniques for cost effectively integrating oxygen-enriched combustion in industrial process heating equipment while maintain or improving NOx emissions, equipment life and product quality.

Stakeholders
Industries such as glass, cement, steel, foundries, die casting, metal melting; equipment suppliers installers; and R&D groups, including universities and natural gas utilities.

Background and the State-of-the-Art
A number of furnaces, especially in the glass and steel industries have successfully partially or fully converted to oxygen-natural gas. Conversion to oxygen is expensive, requires significant modifications to fired equipment, piping and controls and is not cost effective in many applications. Oxy-enriched air does not require these modifications and could be a more suitable for many applications. New membrane and other methods can potentially reduce the onsite production costs increasing its attractiveness.

Justification
Medium to high temperature industries use expensive furnaces, generate high levels of NOx, consume large amounts of natural gas and are typically less than 50% efficient. Use of oxygen-enriched air, generated onsite, can improve furnace performance.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

36. Supercritical CO2 Cycles for Heat Recovery/Power Generation

Issues or Barriers
High cost, low efficiency, reliability and complexity of heat recovery/power generation systems, ineffective collaboration between R&D community, users and suppliers.

Initiative Description and Purpose
Develop heat recovery/power generation/CHP systems for natural gas-fired equipment based on supercritical CO2 cycles which offer reduced costs, higher efficiencies and reliabilities than other approaches and effectively transfer the technology to the market.

Stakeholders
Industrial and commercial natural gas users, equipment suppliers, and installers; R&D organizations including universities and natural gas and electric utilities.

Background and the State-of-the-Art
A number of technologies have been developed to recover heat from moderate temperature waste streams and to convert it into power. Most of these are based on recovering the energy to heat combustion air, which increases NOx emissions, or to heat water to drive steam turbine or an organic Rankine cycle. Use of supercritical CO2 provides higher efficiency energy recovery either back into the process or into a combined heat and power (CHP) cycle. Process footprint and cost are reduced.

Justification
Industrial waste streams from natural gas –fired equipment is estimated to equal energy in 1 TCF of natural gas nationally, representing a large opportunity for heat recovery and onsite power generation.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

37. Use of Onsite Waste Heat to Recover Water

Issues or Barriers
Lack of available technology

Initiative Description and Purpose
Develop cost effective technologies to use the available onsite waste heat for water recovery from onsite waste water containing steams

Stakeholders
Industrial and commercial natural gas users, equipment suppliers and installers; R&D organizations including universities and natural gas and water utilities, municipalities.

Background and the State-of-the-Art
Technologies are currently not available

Justification
A wide range of waste streams on industrial and commercial sites contain water vapor and/or heat. Often, both water and waste heat are available in the same stream, e.g. flue gases. Proportion of heat to water varies depending on the process. For example, direct-fired dryers contain high moisture to heat, while other streams, e.g. flue gases from fluid heaters without economizers contain higher heat to moisture ratios.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

38. Direct Conversion of Low Level Waste Heat to Power

Issues or Barriers
Distributed resource, high capital costs, low conversion efficiencies, ineffective heat sinks, low reliability, ineffective collaboration between R&D community, users and suppliers

Initiative Description and Purpose
Large amounts of energy are lost in the form of low level waste heat. There are no practical or economically attractive methods to recover this energy in a useful form. Projects would develop and demonstrate direct low temperature easily scalable waste heat to power concepts that are low cost and provide high conversion efficiencies. Promote collaboration between R&D community, suppliers and users for effective technology transfer.

Stakeholders
Industrial and commercial energy users, equipment suppliers and installers; R&D organizations, including universities and natural gas and electric utilities.

Background and the State-of-the-Art
A number of technologies, primarily based on thermo-electric concepts, have been investigated, but so far key barriers identified have not been effectively addressed.

Justification
Natural gas is the primary source of fuel energy source in industrial and commercial thermal equipment. Low level waste heat (<450ºF) accounts for 1 to 2 QBtu of energy annually, representing a large opportunity for energy savings, GHG emissions reduction, onsite power generation and economic activity.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
  GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

39. High Efficiency Low Emissions Air Heating

Issues or Barriers
High equipment costs, low efficiencies and inadequate life for indirect heaters, indoor air pollution and/or product contamination with direct fired air heaters. Inadequate collaboration between R&D community, end users and equipment suppliers.

Initiative Description and Purpose
Develop and demonstrate compact, low cost air heating technology that can achieve over 90% thermal efficiency while generating ultra-low levels of NOx, combustibles and particulates. Promote collaboration between R&D community and commercializers.

Stakeholders
Many industrial and commercial facilities use hot air for drying/curing/cooking/baking processes and/or for space heating, generate steam; air heater manufacturers and installers; R&D organizations, including universities and natural gas utilities.

Background and the State-of-the-Art
A number of direct and indirect air heating technologies are available providing various levels of cost point, efficiencies and emission levels, but there are significant opportunities for technological improvements to lower costs, smaller footprints and less equipment complexity, increased efficiency and reduced air emissions.

Justification
Air Heating consumes large amounts of natural gas in industrial and commercial applications. Even a small increase in efficiency of fluid heaters can result in large energy savings and GHG reductions.

Ratepayer Benefit
Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost x
x Economic development

Name of Initiative:

40. Enhanced steam generator efficiency through intelligent demand-following

Issues or Barriers

Steam boilers are used for a large number of industrial manufacturing processes and in commercial buildings and complexes. Because of the differences in these business enterprises, there is a wide variation in the demand and utilization of steam. For example, steam demand may change during the day, working week, and season, or due to production schedules. Despite these variations, current state of the art ultra-low-NO_X combustion systems for boilers have been designed to achieve their highest efficiency and lowest emission levels when operating at full load. Due to this basic design philosophy, boilers are often operated at full load and turned on and off to match steam demand. The on-and-off operation, while effective, wastes energy because of the purging requirement at every startup. Having turndown capability i.e. reduced firing rate, to match the steam demand is a much more energy efficient approach. However, most current boilers can only achieve demand following by trading-off efficiency and emissions. Recent advances in combustion and control technologies provide an excellent foundation for the development of combustion systems for new or retrofit boilers capable of achieving high rates of turndown (10:1) while meeting stringent emissions limits. This would enable industrial and commercial enterprises to operate their boilers in a more efficient manner and reduce natural gas consumption. The key technical challenges in developing demand following steam boilers reside in smart integration of the advanced combustion system and boiler control. Currently, combustion systems with demand following capability are high-cost premium products and typically do not meet California emission standards across their full range of operation. By lowering the cost of such products and improving the full range of emission characteristics market penetration of such boilers will increase.

Initiative Description and Purpose

The purpose of the initiative is to develop and demonstrate a natural gas combustion system for boilers capable of high rates of turndown (10:1) while maintaining low emissions (< 5ppm NO_x @ 3% O_2). The collaborators are national lab, universities, natural gas utilities, equipment manufacturers, and end users. Many installed boilers are over 30 years old, providing a large market for new and retrofit boilers. The geometry of new boilers is not expected to vary greatly from existing systems due to manufacturing costs and installation requirements. Through innovations in burner design and intelligent control protocols, the high turndown combustion system will be designed to work with new or existing boiler designs by taking into account the size, shape, and interconnections of existing boilers. The success and key findings identified by the recently completed Super Boiler project funded by the CEC, DOE and other state agencies will be the launching point when developing the high turndown combustion system. Additionally, analyses identifying the optimum crossover point for process efficiency, system efficiency, and emissions for the combustion system and boiler will be included to develop a holistic approach to demand-following.

Stakeholders

Commercial boiler and boiler burner manufacturers
End-users of boilers

California rate payers
California utilities
Air quality management boards
Research universities
National laboratories and other research institutions

Background and the State-of-the-Art

Boilers in the US are aging rapidly with 80,000 plus units 30 or more years old. In response, the Super Boiler program, a combined DOE and CEC effort was launched to increase boiler system efficiency while reducing pollutant emissions. The Super Boiler program has recently demonstrated advanced boiler technology at three locations, including one in California. The next generation advanced combustion systems being developed for boilers will need to be scalable to both large and small package boiler units as well as adaptable as retrofits for installed boilers. As with Super Boiler, the vast majority of boiler combustion systems are able to operate with at best a 4:1 turndown ratio, limiting the ability of the boiler to follow steam demand. As a result, these boilers are forced to shut down periodically until the demand for steam increases. During these shut down periods the boiler cools, wasting energy that was used to heat the boiler water drum. Restarting the boiler combustion system is an inefficient process that poses safety risks. Prior to restart, operational codes require that boilers be purged with cold air by completing four full air changes, a process that extracts heat from the boiler, wasting previously utilized energy. Boiler restarts can cause stress failure due to thermal shock and maintaining a minimum boiler temperature is desired. Boiler start up poses a safety risk, as a number of steps must be successfully accomplished to light off a large amount of natural gas. By increasing combustion system turndown ratio, boilers can be operated at very low fuel loads, minimizing the need to completely shut off the boiler, reducing thermal stresses and mitigating a safety issue. A number of commercially available boilers are equipped with combustion systems capable of turndown rates of 10:1 or greater. However, these systems are priced at a premium level and are only able to meet the emissions standards in California at higher loading levels, limiting their operational potential in California. Boilers that are able to meet California emissions requirements utilize complicated hardware, require advanced controls algorithms, and are not as durable as their more polluting counterparts. Boiler manufacturers are openly looking for cost-effective high performance burners with high levels of turndown that can meet California emission requirements. Boilers fitted with electric heating elements are capable of following steam demand while producing no pollutants. These boilers are not widely adopted as life cycle analysis reveals their operating costs to be significantly higher than natural gas boilers. Additionally, wide spread adoption of electric boilers in California would put additional strain on the electric grid.

Justification

Boilers are prevalent in all aspects of the industrial and commercial sector. In California, a large fraction of boilers are located in non-attainment areas and must adhere to strict emissions regulations. Boilers are typically oversized when installed to accommodate current and projected steam demand. Increasing the turndown ratio of these oversized boilers will improve their operational efficiency and reduce the number to times they need to be stopped and started. The advanced age of boilers in California provides the opportunity

to improve overall state boiler efficiency through the development and installation of clean burning high turndown (10:1) combustion systems. Aged boilers can either be complete replaced with a new package boiler unit or be refurbished and retrofit with an advanced combustion system. In some instances the combination of retrofitting an older large boiler with a high turndown combustion system can be accompanied with the installation of a new high efficiency unit. The new unit would provide a base load of steam while the older unit could be ramped up and down to meet steam demand. Such retrofits or replacements of low turndown boiler combustion systems would reduce the burden on California's natural gas system and lower ratepayer expense through increase operational efficiency.
This strategy will provide natural gas ratepayer benefits through:
• Enabling the industrial and commercial sectors to reduce natural gas consumption by allowing their boilers to follow steam demand.
• Successful development of high turndown combustion systems will have maximum technology potential for boilers used in the industrial and commercial sector.
• Maximum market potential will be attained through combustion systems for retrofit and new package boilers that are compatible with currently installed boiler configurations.
• Enhancing expected Super Boiler benefits including reducing anticipated ROI of 3-5 years for industrial and 5-7 years for commercial installations while increasing total natural gas cost savings in the South Coast Region beyond the anticipated $15 million.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

41. Low Emissions technologies for industrial applications

Issues or Barriers
Air quality regulations have a significant impact on product availability for a variety of appliances and equipment used in California markets. This is particularly true in SCAQMD and SJUAPCD territories where ultra-stringent emission limits require manufacturers' to develop and produce burners for products specifically for sale in only these markets, which can and has had a significant impact on the cost of these products. As it is becoming increasingly necessary to improve combustion efficiency while reducing CO2 and NOx emissions, the impact on the cost of burners for appliances and gas combustion equipment will continue to rise.

Initiative Description and Purpose
Development of cost-effective burner technologies for use in residential, commercial and industrial gas fired appliances and equipment that are more energy efficient and emit lower amounts of greenhouse gases and NOx.

Stakeholders
DOE, EPA, CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Existing emission requirements for the following appliances and equipment are the strictest in the country and allowable emissions will continue to be reduced in the future:
• Boilers – currently 9 - 12 ppm NOx, expected to be reduced to approximately 5 ppm NOx
• Residential Furnaces and water heaters – currently 40 ng/joule NOx, expected to be reduced to approximately 10 ng/joule NOx
• Industrial Furnaces - currently 60 ppm NOx, expected to be reduced to 20 – 40 ppm NOx for processes operating at < 1,250 °F, 40 ppm NOx for processes > 1,250 °F

Justification
• Energy Efficiency
• Greenhouse gas reduction
• Broad application of the technology
• Cost reductions for constrained markets

Ratepayer Benefit
x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation

Name of Initiative:

42. CO Control System Development & Demonstrations

Issues or Barriers
In many industrial and commercial combustion control applications, using CO control instead of the traditional O2-trim is superior in fuel savings and NOx reduction. CO-control system is a proven technology that is commercially available but not yet widely adapted. Research and demonstrations are needed to replicate the technology and successes in California, and to explore if it can be adapted to medium and smaller commercial sized boilers and fired heaters. Current obstacles can be overcome by reducing the initial costs and increasing consumer's understanding and support.

Initiative Description and Purpose
CO control, similar to the traditional O2-trim feedback control system, provides the balance of combustion efficiency and NOx reduction can be optimized in a more responsive manner in a tighter window. We need to provide the public demonstration and showcases, and make it more affordable to a wider spectrum of applications.

Stakeholders
Utility companies who use combustion based generation, industrial, oil refineries and large commercial customers, who use fired heaters and boilers, are prime candidates. Ratepayers will indirectly benefit from it.

Background and the State-of-the-Art
Private technology vendor, such as Bambeck Systems, has a few installations that are proven successes. The initial cost is not affordable in small scales, though. Most of operational and maintenance professional need to become comfortable with this new and emerging technology.

Justification
Will provide natural gas ratepayer benefits, with estimated of annual savings/benefits in California:
• Utility generation; refinery heaters; large industrial and commercial fired heaters and boilers – affecting 1 BCF/day with 2% savings in natural gas fuel, 10% minimum reduction in associated NOx emissions
• Maximum technology potential, if successful – triple of the above estimate
• Maximum market potential, if successful – customer adaptation rate increased from under 5 to 20 per year.

Ratepayer Benefit
Promote greater reliability
x Lower costs
x Increased safety
Societal benefits

x GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative:

43. Advanced Engine Control Systems for Water Pumping

Issues or Barriers
Municipal water pumpers operating in the SCAQMD continue to struggle to meet permit limits on a continuous basis. The engine regulations in SCAQMD require operators to check NOx and CO emissions either weekly with a portable analyzer or continuously with a continuous emissions monitoring system (CEMS). If engine emissions are above permit limits, regulations require an operator to shut the engine down within one hour.

Initiative Description and Purpose
The purpose of this work would be to fund the demonstration of new engine control technologies at multiple demonstration sites to give operators some confidence in these new products. Over the last four years several new engine emission control systems have been developed to address lower emission requirements and to meet permit limits on a continuous basis. Several new control systems were introduced for sale into the market in early 2012, but like many new products, have been slow to be adopted without a record of successful demonstration.

Stakeholders
Engine operators, Local air districts, and Manufacturers of new emission control products

Background and the State-of-the-Art
Older engine emission control systems have struggled to meet permit limits on a continuous basis. Because of this problem, SCAQMD amended its engine rule in 2008 which requires engine operators to validate compliance with permit limits on a weekly basis (for engines under 750 HP) or on a continuous basis (for engines over 750 HP). In 2011 / 2012, Tecogen, Continental Controls, AETC and Woodward all released new control system products into the market for use with rich burn engines. In addition, Jenbacher offered an advanced SCR based system for lean burn engines. All of these products have been successfully demonstrated in southern California. However, additional demonstrations of these new technologies would help promote the adoption of these products into the marketplace. Operators have been reluctant to purchase new technologies without sufficient background showing successful use and reliability of the new products.

Justification
There are approximately 660 engines operating in the SCAQMD with the majority being rich burn engines. In addition, there are 1,000 or more engines operating in the other southern California air districts that could also benefit from use of improved engine emission control technology.

Ratepayer Benefit
x Promote greater reliability

Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative:

44. Waste Heat Recovery (WHR) – High Temperature Flue Gases

Issues or Barriers
Waste heat recovery of high temperature fluids can only be achieved through heat exchangers that can be used to produce steam and/or an Organic Rankine Cycle (ORC) to produce electricity, currently. One of the major issues with recovering heat to produce electricity is that recovering flue gases to produce electricity is considered "fuel switching" and thus such projects are not eligible for incentives from the state. This is true regardless of whether the system produces steam to drive a steam turbine or heat is recovered to drive an ORC. The second is that the costs to harness flue gas energies in a manner that can be received by a steam turbine or ORC are exorbitant.

Initiative Description and Purpose
Development of affordable heat exchangers and/or ORC systems that can be applied to industrial systems to efficiently recover waste heat streams to produce electricity. System development should include heat exchanger material and manufacturing processes that reduce cost.

Stakeholders
DOE, CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Steam turbine and ORC generation technologies are well known and exist in the market place. However, cost has prevented these technologies from being used on a larger scale. As the need to reduce greenhouse gases has proliferated and the cost of energy has increased the cost effectiveness of such systems is increasing. ORC systems, in particular, are commonly utilized in other countries to increase the efficiency of energy use, reduce the need for traditional power plant generation and coincidentally reduce greenhouse gas production.

Justification
• Energy Efficiency
• Greenhouse gas reduction
• Electricity peak load reduction

Ratepayer Benefit
x Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost

Name of Initiative:

45. Waste heat usage in reverse osmosis plants

Issues or Barriers
Electricity is the highest cost in operating a reverse osmosis plant. Utilizing natural gas driven pumps can take advantage of the large spark spread in California to reduce plant operating costs. In order for a plant to take advantage of gas technology however, there must be a use for the waste heat.

Initiative Description and Purpose
There are a variety of potential applications for waste heat in plant operations. More research needs to be done to determine the most effective use of this heat and quantify the economic benefits.

Stakeholders
DOE, SCAQMD, SCG

Background and the State-of-the-Art
Reverse osmosis plants have been operating for 50 years and the technology is in a mature state. There have been two main uses for waste heat in plant operations: heating the intake water to reduce required pumping pressure, and evaporating a portion of the concentrate. The latter method results in the environmental benefit of reducing the amount of concentrate released into the ocean and an economic benefit from selling salt blocks. There is also an experimental method which pumps exhaust gas through the concentrate in order to precipitate dissolved solids for collection. More research needs to be done to
determine which of the above would be best practices for California plants and work with the industry to determine any additional waste heat applications.

Justification
There are currently plans to construct large reverse osmosis plants in Southern California. These plants will be a valuable new source of fresh water but will increase electricity demand for a region that is already experiencing supply issues. There is an opportunity to decrease the amount of electricity required and reduce plant operation costs but the benefits cannot be fully quantified until best practices for waste heat utilization are determined.

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
  GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative:

46. Compact Digital Gas Flow Meter

Issues or Barriers
Natural gas flow metering traditionally is done by diaphragm or rotating disc type analog meters with bulky volume for discrete and cumulative readings. They cost hundreds of dollars each. For residential and commercial appliances, and end use testing and measurement trades, it posed a significant challenge in space constraints. Real time readings and automation are much more limited, as compared to the electric circuit transmitter sensors. Currently, the advanced gas meters in deployment would have to be adapted with pulse generators to provide output signal, and the data could not be real-time. Although some alternative gas mass flow sensors can remedy, they cost thousands of dollars and cannot be widely used or integrated to produce smart appliances, as contrast to the smart electric appliances.

Initiative Description and Purpose
We need to provide assistance in product research and development, market adaptation, public demonstration and showcases, and make gas metering compact, accurate, digital, and affordable to customers and rate payers.

Stakeholders
Residential, small and medium size commercial customers, home automation industries, appliance manufacturers, and testing/monitoring/verification trades will benefit. Ratepayers will directly or indirectly benefit.

Background and the State-of-the-Art
Current obstacles in gas metering can be overcome by using micro-electronics, actuators, and micro-systems (MEMS) technology. MEMS has the potential to bring a revolution to the advanced meters, smart gas appliances, and home automation industries. Private technology innovators and manufacturers, such as Omron, have proven successes and a low cost, low capacity model for sale currently. Omron indicated that a larger capacity model, suitable for the currently largest home appliance rated at 200,000 Btu/hr, is being in development and may become available in early 2013. Omron had postponed the production a few months – an indication that outside assistance and co-funding may be needed to break through.

Justification
Will provide natural gas ratepayer benefits, with estimated of annual savings/benefits in California:

- Residential and light commercial customers – affecting at least 1 BCF/day with 1% conservative minimum savings in natural gas fuel
- Maximum technology potential, if successful – ten times of the above estimate; compounded in revolutions from advancing the advanced meter industry as a whole

- Maximum market potential, if successful – high but difficult to estimate. MEMS has the potential to bring a revolution to the advanced meters, smart gas appliances, and home automation industries.

Ratepayer

Promote greater reliability
x Lower costs
x Increased safety

Societal benefits
x GHG emissions mitigation at the lowest possible cost

Economic development

Name of Initiative:

47. Solar Thermal Process Steam

Issues or Barriers
Many of the agricultural processing companies in the State of California have significant thermal loads distinct from relatively low temperature hot water. These loads are typically for cooking, sterilizing, pasteurizing and drying. Some of the target industries would be dairy products, wine and beer production, and vegetable processing. The intense solar radiation in southern California makes it an ideal location for the generation of process heat from solar energy. The barriers to implementation include the low cost of natural gas, the availability of vacant land adjacent to an existing facility, and the high cost of solar thermal systems that operate at the high temperatures needed by these industries.

Initiative Description and Purpose
Combined Power LLC has developed a low cost solar thermal system capable of >30% optical efficiency and (>300^{o} C/>572^{o} F) heat. Thermal oil is used as the heat transfer medium that can be used directly or as a heat source to produce steam. The solar thermal energy used during the daylight hours, when most work is done, reduces atmospheric emissions.

Stakeholders
CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Solar thermal power generation has focused on large facilities and exclusively electrical power production. Combined Power has focused on small-scale solar thermal built from low cost materials. Their Hyperlight® system has been demonstrated at full scale geometry in a one-quarter size installation. Combined Power has broken ground on its first full-size commercial-scale installation in Brawley, California.

Justification
• Energy Efficiency
• Greenhouse gas reduction
• Particulate airborne emission reductions

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost

Name of Initiative

48. Algae-based agricultural water treatment

Issues or Barriers
Many agro-industry facilities generate wastes and wastewater that have very high concentrations of organics and nutrients, specifically nitrogen and phosphorus. These wastes are usually disposed through land application. Crops are then planted on the land which uptake the nutrients. As a facility increases production, they must procure more land for application. Anaerobic digestion followed by algae growth is an alternative to the traditional direct land application of wastes or wastewater. This approach reduces the footprint for waste disposal while generating the value added products of renewable natural gas and algal biomass. The Algal biomass can then be used as cattle feed, processed for specific organic compounds (e.g., astaxanthin), or algal oil. This approach produces renewable energy and protects that environment from excessive nutrient loading.

Initiative Description and Purpose
This initiative will target dairies as an opportunity for manure and parlor wastewater anaerobic digestion with algal growth on the digested liquid. This approach will reduce the environmental impact of large dairy farms providing opportunity for increase their herd size. It will also introduce an additional revenue source from algal biomass products.

Stakeholders
CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Dairies currently collect liquid manure and process water for direct land application. Very few dairies in the State of California have anaerobic digestion. Currently, no dairies in the state use algae for nutrient recovery.

Justification
• Energy Efficiency
• Greenhouse gas reduction
• Water quality improvement
• Carbon dioxide recycling

Ratepayer Benefit
x Promote greater reliability
x Lower costs
  Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost

Name of Initiative

49. Algae-based CO_2 recycling

Issues or Barriers
In many areas of southern California, airborne emissions from power generation, internal combustion direct drive applications, and boilers contribute to the degradation of ambient air quality and increase atmospheric greenhouse gases. Using available water scrubbing technology, CO_2 and other pollutants can be removed from the stack gas by dissolving in water. The CO_2 laden water can then be used as feedstock for the production of algae. Thus, the CO2 from fossil fuels can be recycled into algae for use as cattle feed or the production of renewable fuels. The barrier to this technology is a cost effective photobioreactor for the production of algae.

Initiative Description and Purpose
This initiative will target natural gas fired water pumping in the central valley or Riverside County. The stack gas will be scrubbed to recovery the CO2 and then used for the production of algae. On-site solar thermal will be used to process and dry the algae.

Stakeholders
CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Currently, natural gas fired internal combustion engines are used for electricity production and water pumping across southern California. These emissions are not treated for pollutant reduction. Pressurized water or acid water scrubbing will be used to dissolve the CO_2 gas into water.

Justification
• Energy Efficiency
• Greenhouse gas reduction
• Carbon dioxide recycling

Ratepayer Benefit
x Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost

Name of Initiative:

50. Low cost ADG/fuel flexible DG/CHP for applications at small to medium Waste Water Treatment Facilities (WWTF)

Issues or Barriers
Current ADG DG/CHP systems range in price from $3000 - $6000 /kW installed at a typical WWTF. This cost barrier inhibits the adoption of such systems at all but the largest WWTF

Initiative Description and Purpose
Low cost (<$1500 / kW installed) DG/CHP systems with nominal capacity of 250 kW or less (single or multiple units) and with overall operational and maintenance costs consistent existing ADG fueled DG/CHP systems will find great acceptance at small to medium WWTF where the large capital costs of existing systems are prohibitive. Added maintenance costs are possible but over a nominal 10 year life, the low cost system must have amortized O&M and general operational costs equal to or less than conventional systems.

Stakeholders
WWTF (LACSD, EMWD), Prime Mover manufacturers (Mazda North America)

Background and the State-of-the-Art
Utilization of carbon neutral ADG from waste water treatment facilities has long been capitalized upon with installation of large turbines or reciprocating engines and of late, fuel cells. At smaller facilities, the current state of the art is the Capstone Microturbine. However even this with costs of nominally $4000/kW turnkey is prohibitively expensive. As such, most small to medium capacity facilities to do not maximize the potential of their onsite fuel source, capturing a portion for digester heating and flaring the balance.

Justification
Small WWTF are generally defined as those with <1 million gallons or effluent / day (MGD) processing capacity while medium are approximately designated as between 1 and 20 MGD. In the State of California, there are over 250 WWTF rated as medium and larger with a capacity of over 1 MGD. Of these 110+ have digesters to reduce sludge volume/discharge and produce anaerobic digester gas (ADG) as a by-product. This methane rich (40% - 60% by volume methane) gas is a valuable carbon neutral fuel source for California (and the US and World). For the existing 110+ digesters in California, nominally 17 billion cu-ft of ADG is produced per day representing the potential for approximately 125 MW of carbon neutral generation for the electric grid as well as 6.4 trillion btu of thermal energy. Currently, only approximately 35 MW of power is generated leaving an opportunity given the existing infrastructure of approximately 90 MW. Additional improvements in digester technology will increase the gap between deployment and potential significantly as well as exploitation of currently untapped potential (all forms of existing sludge treatment (aerobic as well as anaerobic),

deployment of digesters at facilities that do not currently process their sludge, processing of new sources of waste such as restaurant grease and oil, food processing and dairy waste) the potential for ADG production increases to 450 MW. If all of the ADG potential is realized and utilized through the deployment of DG/CHP systems, the incremental increase in power production would be 415 MW. With 365/24/7 production of ADG, the maximum annual electric energy potential would be 25,450 GW-hr and a thermal output of approximately 130 million MMbtu. This results in a net annual carbon reduction of approximately 58 MMT/CO2 from offset central power plant production and another 7 MMT/CO2 of displaced natural gas consumption for the thermal component.

Ratepayer Benefit

Promote greater reliability
x Lower costs
Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Natural Gas – Proposed Research Initiative

Program Area:

Renewable Energy Research.

Reduce barriers and increase penetration of renewable energy by advancing the science, technology, and market availability of combined heat and power (CHP) and other renewable processes; develop hybrid generation and other low emission natural gas technologies for distributed generation; and develop and demonstrate diversified applications of advanced generation technologies that use renewable natural gas. Note that renewable generation (other than use of renewable gas) is funded in PIER-E or EPIC.

Name of Initiative

51. Integrated Absorption Process for Upgrading Renewable Natural Gas

Issues or Barriers

The technology is based on a patent application held by our company that deals for a two-stage renewable natural gas upgrading process that upgrades biogas to pipeline quality and utilizes some of the captured carbon dioxide. The market adoption of the technology requires slip-stream and full-scale experimental evaluations.

Initiative Description and Purpose

The successful adoption of the technology will help in the cost effective production of renewable natural gas from wastewater treatment plants and landfills for a direct substitute for conventional pipeline supplies that can be used for transportation and other energy sectors. Processes currently used for upgrading the gas streams include pressure swing adsorption (PSA), conventional membrane processes, and conventional absorption processes using packed columns with amine or other absorbents. However, these processes are generally too expensive for the small flow rates of renewable natural gas streams available at wastewater treatment plants and many landfills. By small flow rates, we mean flow rates in the range of about 10 ft^3/ min to about 1000 ft^3/ min.

Stakeholders

Operators of waste water treatment plants, landfills, and digesters would befit by turning waster materials to valuable product. Natural gas companies would benefit from introducing renewable sources into their delivery system. Natural gas vehicle owners would benefit from a cost effective energy supply for their vehicles.

Background and the State-of-the-Art

The main objective of the technology is to provide a process for upgrading raw biogas to pipeline-quality gas specifications which can be used to process the small biogas flow rates typically associated with wastewater treatment plants and landfill gas sites.

The technology is a two-stage biogas upgrading process utilizing packed column absorbers and/or gas/liquid membrane contactors for wastewater treatment facilities, landfill gas upgrading and other biogas treatment facilities which remove CO_2 as well as H_2S from the raw product gas.

The sour water generated in the first stage may beneficially be used to control pH, such as in a wastewater treatment facility or in a landfill gas treatment facility to improve biogas production or to neutralize alkaline effluents may be present. In addition to sour

water utilization being integrated between the CO_2 removal process and the biogas production process, heat utilization is integrated between the CO_2 removal process and the solvent regeneration process. In addition, compared with amine-only systems, the process can be run with smaller equipment and may be self-sufficient for thermal loads to regenerate the solvent. This latter fact is important because most wastewater treatment facilities do not have boiler systems and auxiliaries such as boiler feed water purification. The anticipated contact device operates with very high mass transfer rates resulting in smaller equipment with a much smaller volumetric footprint.

Justification

In the United States, biogas vehicle activities are on a smaller scale compared to other industrially developed nations in Europe (e.g., more than half the gas used in Sweden's 11,500 natural gas vehicles is biogas, Germany and Austria are targeting 20% biogas in natural gas vehicle fuel). In California, the natural gas use for transportation section is less than 1% implying considerable market potential. Natural gas vehicles can reduce pollution and greenhouse gas emissions generated by most vehicle sources, from commuter traffic to delivery trucks and refuse haulers to port trucks. According to a November 2008 study by the Institute for Economic and Environmental Studies at California State University, Fullerton, air pollution in Southern California and the San Joaquin Valley alone costs California $28 billion a year. Owing to its huge economy, the state is the 12th largest emitter of carbon in the world. Renewable gas supplies will further reduce the carbon footprint of pipeline gas. Natural gas vehicles powered by the renewable gas will also help reduce California’s oil dependence.

Ratepayer Benefit

- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

52. Demonstration of Thermo Chemical Energy Recuperation (TCER) on a Stationary Natural Gas Engine

Issues or Barriers

The critical success factor for development and commercialization of Thermo chemical Energy Recuperation technology for high efficiency, ultra-low emissions engines is to demonstrate that low temperature hydrogen generation using waste heat from the engine can sustain endothermic reforming and to ensure that the natural gas engine receiving the fuel reformate has the required “intelligent controls” for responding to potentially small changes in fuel properties.

Initiative Description and Purpose

Thermo chemical energy recuperation entails the capture of exhaust heat to increase efficiency and simultaneously lower the emissions of a heat engine. Typically this is done by powering an endothermic reformation reaction to create hydrogen which then enables low temperature combustion regimes when this new fuel is directed to the engine intake. Critical issues such as engine stability and low emissions have been proven but the stable reformation step and harvesting of exhaust heat remains a critical enabling area. We propose an initiative to further understand and develop the thermo chemical energy recuperation technology for engines so that it might be commercially implemented.

Stakeholders

Direct stakeholders are those interested in selling, operating and serving stationary, natural gas-fired power plants in the 300 kW to 5 MW range. In addition to CEC, Southern California Gas, Cummins, DOE and other gas companies have supported development of TCER. Many major engine OEMs including Cummins, GE Waukesha, CAT, GE Jenbacher and others are interested in minimizing thermal losses from their engines and reducing emissions. Several have also independently evaluated the benefits of operating their engines on hydrogen enriched fuel. Cummins would be interested in supporting successful demonstration of this technology. With support from DOE, ORNL is performing research on thermo chemical energy recuperation for engines.

Background and the State-of-the-Art

Thermo chemical energy recuperation in Natural Gas engines and the steps thereof have been investigated for the past several years by a handful of research groups. UC Davis has published results of theoretical investigations with liquid-fueled engines and has experimentally demonstrated several sub-steps thereof. UC Davis and City Engines (formerly Collier Technologies) demonstrated the real benefits of natural gas-hydrogen blends in reduced emissions, longer engine life, and higher efficiency. With support from the CEC under CEC 500-06-038, GTI and Cummins conducted open-loop demonstrations of the natural gas engine technology and confirmed the potential for the

technology to yield efficient engine operation and control. At the conclusion of this project, GTI and Cummins conducted a closed-loop attempt at thermo chemical energy recuperation where hydrogen was generated from the exhaust heat. Although the closed loop attempt could not be sustained for more than a few hours, it gave valuable insight to the limiting factors affecting the reforming reactions and the control of the engine. These tests confirmed the importance of the proper choice of catalyst and design conditions in maintaining stable conditions of the hydrogen production device. The tests also identified the need for more intelligent engine controls to sense and react appropriately to changes in the performance of the hydrogen production device.

Oak Ridge National Laboratory (ORNL) has published its independent evaluation of the potential for thermo chemical energy recuperation for engines. Based upon their findings ORNL, GTI and UC Davis have initiated efforts that are intended to improve cooperation and leverage capabilities required to address the technology gaps and critical success factors mentioned above. Cummins has also been involved in these discussions. The proposed initiative would build upon the knowledge base and capabilities of the team with the goal of demonstrating sustainable long-term operation of the closed loop thermo chemical engine. This would be accomplished proving out an improved catalytic reactor design for using exhaust heat from the engine to endothermic reforming of natural gas to generate the hydrogen enriched fuel and using “intelligent engine control” designed around the use of a gas quality sensor technology developed by GTI... This initiative will allow the demonstrated benefits of hydrogen-natural gas blend use in engines without a potentially dangerous and costly hydrogen storage and infrastructure and will further the efficiency by using currently wasted exhaust energy to generate the hydrogen. Without the understanding generated from the proposed initiative, thermo chemical energy recuperation for engines will not progress quickly enough to enable California ratepayers to benefit from the lower cost of natural gas in the marketplace.

Justification
If successful the technology will provide natural gas rate payers benefits in lower costs for power and reduced emissions of criteria pollutants and greenhouse gases. Operators of stationary natural gas engines would realize improved engine life, increased efficiency and lower emissions.

One of the advantages of thermo chemical energy recuperation for thermal recovery from engines is that the energy recovered can be used to produce more power. This is an important distinction from CHP because the thermal energy in the jacket water and exhaust from engines is too low to be used for anything besides hot water or low pressure steam. Many facilities in CA simply do not have enough demand for hot water or low pressure steam to justify investment in CHP.

The capital and operating costs of applying Selective Catalytic Reduction on reciprocating natural gas engines is high enough that it constrains the market penetration of new and cleaner distributed generation technologies into California.

Thermo chemical energy recuperation affords a means for higher efficiency, lower installed cost per kW and lower operating costs compared to engines with SCR.

Ratepayer Benefit

- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative:

53. Development and Demonstration of Hybrid, Fuel-Flexible Engine/Turbine Systems to Increase Market Penetration of Distributed Generation and CHP in California

Issues or Barriers

Below about 5 MWe, reciprocating engines are the most economical prime movers for distributed generation (DG) and combined heat and power (CHP). CARB 2007 emission limits for DG present a major impediment for using reciprocating engines for DG and CHP in CA. The CEC has supported emission control technology development and demonstrations to address this barrier. Preliminary research by GTI indicates that the potential exists to build hybrid power generation systems comprised of reciprocating engines and off the shelf turbo-machinery that are capable of meeting the CARB limits without the added expense of expensive after-treatment systems and that also offer lower total installed costs per kWe produced than commercially available products.CEC support for this development and demonstration is required to bring these hybrid systems to the market.

Initiative Description and Purpose

Hybrid, Fuel-Flexible Engine/Turbine Systems will employ staged combustion and staged power generation. In the 1st stage, partial oxidation (POX) of the fuel produces two products: power with thermal losses that can be partially recovered and H_2 –rich fuel gas. The H_2 rich fuel gas is produced instead of CO_2 because combustion is incomplete. In the 2nd stage, completing combustion is performed in a gas turbine using the fuel gas from the first stage either alone, or blended with another fuel such as biogas, produces power with thermal losses which could be partially recovered and used for CHP. The only emissions to the ambient air are exhausted at the second stage. In the preferred configurations, the gas turbine is based upon the use of commercially available turbochargers and available or modified combustors. Preliminary modeling of one hybrid configuration was performed using a CAT engine (400kW, 46% thermal efficiency) in the baseline. The estimated hybrid performance was compared to separately operating the CAT engine with a conventional gas turbine. For the same total (natural gas) fuel input to the CAT engine and a conventional GT versus a Hybrid System, the thermal efficiency for the Hybrid System was predicted to about 23% higher than the sum of separate systems. Based upon prior experimental data with staged combustion and predicted peak adiabatic temperature for combustion, the final NOx emissions are expected to below 5 vppm (@15%O2) without the need for catalytic after treatment or reagent injection.

Stakeholders

The concept (without proprietary details) has been presented to or shared with technical staff of major OEMs including CAT, Cummins, GE Jenbacher and GE Waukesha. We have also begun collaborating with Garrett who is one of the major developer and suppliers of turbo-machinery to the aforementioned engine OEMs. Obviously it is

difficult to confirm that any of these stakeholders support the initiative until such time that they are willing to commit some of their resources to joint development. However, there has certainly been interest and, based upon feedback thus far, there is a high likelihood that we would secure at least one of the major engine OEMs as a partner to develop Hybrid Systems

Background and the State-of-the-Art

A fuel-flexible hybrid system concept is currently under development with support from CEC for demonstration with an existing reciprocating engine operated on biogas (CEC PIR 11-028). This hybrid system represents only one of the possible configurations that have been identified and studied at GTI, and consists of a Partial Oxidation Gas Turbine (POGT) in the 1st stage and lean combustion reciprocating engine in the 2nd stage. This project and future development builds upon over ten years of successful development of a POGT supported by CEC and DOE as well as comparable years developing and commercializing staged combustion boiler-burner systems. Other hybrid system configurations such as one with a partial oxidation engine in the first stage and a combustion turbine in the second stage have been defined and are covered by an existing patent. Internal R&D by GTI indicates that this configuration could offer several important advantages for DG/CHP applications. However, to fully realize the potential advantages for efficiency and emissions, it will require some slight modifications to the design of the reciprocating engine. Engine optimization through planned partnering with an engine OEM along with Ricardo, who brings engine design expertise, is expected to contribute and maximize the likelihood for technical and commercial success.

Justification

By lowering the overall cost of DG, the proposed hybrid technology would help the State to realize the goal of installing 4,000 Megawatts (MW) of additional CHP capacity by 2020 (California Air Resources Board [ARB] AB 32 Scoping Plan).It also appears that fuel-flexible, hybrid systems would address two of the Top Priority Milestones included in the PIER Advanced Generation Roadmap[i]: Industrial Cogeneration: Milestone (3)Impact of Alternative Fuels Use on Industrial CHP Systems and under Advanced Gas Turbine Cycles: Milestone (5)Cost-Competitive, Higher Efficiency Technology Options for Retrofit Applications. It is premature at this time to provide estimates of maximum technology potential and market potential, if successful. Because of involvement an engine OEM and Ricardo, it is expected that products could be introduced into the CA market in as little as three-four years from the start of contract awards from the CEC

Ratepayer Benefit

☐ Promote greater reliability

x Lower costs

☐ Increased safety

☐ Societal benefits

x GHG emissions mitigation at the lowest possible cost

- Economic development: higher fuel to power efficiency, and lower specific cost $/kW

[i]Reference: PIER Advanced Generation Roadmap Final Report - PIER AGen project 500-06-012, Work Authorization Number NCI-06-027-P-R conducted by Navigant Consulting.

Name of Initiative

54. Solar-Natural gas Hybrid Processes

Issues or Barriers
Initial and maintenance system costs, inadequate generated thermal fluid temperatures, system reliability and complexity, lack of coordination between stakeholders, perception of risk, availability of trained staff, inadequate technology transfer.

Initiative Description and Purpose
Develop and demonstrate solar- natural gas hybrid concepts for flexible, reliable and cost effective production of high quality thermal energy for driving onsite heating, cooling and thermal power generation equipment. Promote collaboration between R&D community, users, suppliers and installers and transfer the technology to the market.

Stakeholders
Residential, commercial and industrial energy users, solar equipment suppliers and installers; R&D organizations, including universities; natural gas and electric utilities and ratepayers.

Background and the State-of-the-Art
A wide range of solar thermal collectors exist and are continuing to be developed. Current technologies to save energy by integration with natural-gas fired equipment are expensive and do not generate thermal energy of sufficient quality and quantity to be cost effective.

Justification
Increases use of renewable energy across the natural gas markets by addressing key barriers to deployment.

Ratepayer Benefit
- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

55. Solar Hybrid Thermal-Electric Processes

Issues or Barriers
Initial and maintenance system costs, reliability, lack of coordination between stakeholders, perception of risk, flexibility of electric utility, availability of trained staff, aesthetics and inadequate technology transfer.

Initiative Description and Purpose
Develop and demonstrate solar hybrid concepts for flexible, reliable and cost effective production of high quality thermal and electrical energy for driving heating, cooling and other onsite equipment. Promote collaboration between R&D community, users, suppliers and installers and transfer the technology to the market.

Stakeholders
Commercial and industrial energy users, solar equipment suppliers and installers; R&D organizations, including universities; natural gas and electric utilities and ratepayers

Background and the State-of-the-Art
Current approaches generally involve recovering heat from PV arrays using a thermal fluid and are expensive, offer no control over generated power to heat ratio and are susceptible to damage with any thermal upsets.

Justification
Increases deployment of renewable energy by addressing key barriers.

Ratepayer Benefit
- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

56. Optimal use of local generation resources

Issues or Barriers
On-site generation (natural gas and renewable) has many potential benefits, including helping to provide local reliability (particularly when coupled with local storage), reducing customer costs (when grid prices are high), and reducing carbon emissions and further reducing costs (when the waste heat can be utilized for local purposes). The desire for power availability when grid power fails is increasing as people observe this occurring personally or on the news. A problem that arises is knowing when to run the on-site generation, at what capacity, and at what balance between heat and power. Optimizing this helps both the customer and the utility grid.

Initiative Description and Purpose
Our initiative will directly address this problem by creating a “local price” for electricity within the building. In many cases, this will replicate the grid price (and price forecast), but will deviate from it in several circumstances. One is when grid prices are high but local generation (and storage) are sufficient for the building’s needs. Another is when the grid is absent, in which case there is no grid price to use. Setting the local price takes into account the cost of natural gas, the value of waste heat (zero when there is no local need for it), the status of local storage, the grid price, a possible lower price from the grid for purchasing power from the building, and the capacity of local generation, storage, and demand. Equipment that uses the largest amounts of electricity can then use the local price to behave optimally, and as they change their behavior, the price will stabilize.

A first step would be to create a simulation model of a few key end uses, local gas generation, local storage, and utility price streams, to test various algorithms for operating the local generation and storage for maximum benefit to both the customer and utility. Communication to implement this would be built on top of existing protocols to speed development and deployment in the market. While this concept is new, it could move quickly from prototype to being introduced into the market as the innovations are primarily in software and communications rather than in hardware.

Stakeholders
We have had formal support for this research direction from key personnel at Google, IEEE, and the US Army, and significant interest from many others.

Background and the State-of-the-Art
Our company has developed the concept of a “Nanogrid” that takes the concept of a local price and extends it to networks of local grids. However, for this purpose of managing local gas generation (and accompanying storage), only a single local grid is involved. There are existing technologies such as USB and Power over Ethernet that have digital management of local power distribution, though they presently lack the

concept of a local electricity price. Our company recently authored an article in IEEE Computer magazine on these topics (September, 2012). Our company also has long conducted research on microgrids which directly feeds into this initiative.

Justification
Any building type – residential, commercial, and industrial – could gain economic and/or reliability benefit from local gas generation (and the technology also applies to local renewable generation). Regardless of why people choose to deploy local generation, nanogrids coupled with gas fuel cells will help people realize the best economic advantage. In addition, as local generation becomes more advantageous, additional buildings can be added to the nanogrid. Because the technology is generally useful, at this time it is hard to put a meaningful figure to the energy benefits, or to total the many economic and non-economic benefits, particularly when the grid is unreliable. However, the benefits are certainly large. This technology can also be deployed throughout the country and world and California leadership can contribute to local economic advantage.

Ratepayer Benefit
- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

57. Cost-effective and scalable gas-fuel interchangeable (renewable and natural gas) heating and power systems

Issues or Barriers

The performance of combustion systems is highly sensitive to slight variations in fuel compositions. This has been a major technical barrier for the transportation, heating and power industries to adopt renewable fuels and/or their natural gas fuel blends. Because of this known problem, land-fill-gas is not allowed into natural gas pipelines in California. To circumvent the transportation restriction of biofuels, burning them in stationary systems for heat and power generation on-site or within the neighborhood (i.e. local) seems the best strategy to help meet our aggressive renewable energy and GHG reduction goals. Burners for stationary systems are slightly more tolerant to fuel variations than reciprocating engines. However, they are subjected to more stringent emissions regulations. Some stationary systems have been configured specifically for renewable fuels to meet these regulations but they cannot operate on natural gas or propane without significant performance degradation in terms of lowering efficiency and increasing emissions. Because availability of renewable fuels can be intermittent, not having a fuel-interchangeable option relegates renewable-fuels-only systems to be relatively costly niche products. CEC and the utilities (e.g. SoCalGas) recognize this barrier and are supporting research to develop gas fuel interchangeability indices. However, applying such knowledge to heating and power products of all sizes requires a fundamental design change in the dry-low-NOx (DLN) combustion systems so that they can be responsive to fuel changes without requiring costly peripheries to monitor and control their performances and/or even costlier exhaust gas cleanup. Fuel-interchangeable combustion systems that are competitive in cost, reliability, and performance with contemporary natural gas DLN systems will overcome these barriers to accelerate the penetration of renewable fuels into the California market.

Initiative Description and Purpose

This purpose of the initiative is to develop and demonstrate gas fuel interchangeable DLN combustion systems for commercial to large industrial heaters and power generators. The collaborators are national lab, universities, AQMD, renewable fuel generators, equipment manufacturers and end users. The foundation of the approach is to exploit advanced fuel-interchangeable combustion concepts that are compatible in size, shape, and functionality with most existing equipment. Proven concepts developed by research institutions and equipment manufacturers will be sought. The fuel interchangeable indices from a current CEC study will be used to determine their fuel-interchangeability potential. The performances of the burner in terms of fuel acceptance (i.e. renewable fuel, natural gas and their fuel blends), flame stability, flame size, flame shape, combustion efficiency, emission, and turndown will be determined and compared. Prototype systems for the higher ranked concepts selected by an independent advisory committee will be developed and demonstrated in a boiler simulator and/or a gas turbine combustor simulator. The outcome of the initiative is to

confirm that new combustion concepts can address the issues brought about by interchanging between renewable fuels and natural gas. That these systems can be retrofits and do not increase the size, the foot print, or limit the deployment readiness of the systems will ensure market acceptability and eventual penetration.

Stakeholders

Commercial to large-industrial heating equipment manufacturers
Micro turbine and mega-watt size gas turbine manufacturers
End-users of heating and power equipment
Renewable fuel generators
California rate payers, California utilities and AQMD
Research universities, national laboratories and other research institutions

Background and the State-of-the-Art

Though the effects of changing fuels on DLN systems have been well documented, research and development of gas-fuel interchangeability combustion systems have mainly focused on hydrogen-syngas-methane blends for the gas turbines in an Integrated Gasification Combined Cycle (IGCC) plant. Hydrogen is an energetic fuel. Results from the DOE Office of Fossil Energy projects show that operating hydrogen in a gas turbine required fundamentally different combustion concepts. On the other hand, renewable fuels are less energetic than natural gas. Studies have shown that natural gas burners can be re-tuned for renewable fuels. Products are available in the market for specific types of renewable gas fuels but meeting the stringent emissions standard in California remains a great challenge. Truly fuel-interchangeable and clean equipment for heating and power are not widely available. The main technical challenge is to maintain a stable flame when burning the weaker renewable fuel while not causing flashback when switching to the more robust natural gas flame. In the past two decades, several ultra-clean burner ideas have been developed for DLN systems and they are ripe for fuel-interchangeable developments. The surface stabilized burner concept pioneered by Alzeta Corp. and the low-swirl burner developed at Lawrence Berkeley National Lab. (both received funding from CEC DOE) have found their ways to industrial heating products, and have also been demonstrated in gas turbines. The basic premise behind these burners is to promote more stable flames by reducing the levels of shear turbulence. Through DOE support, a fuel-flexible low-swirl burner (hydrogen/syngas/natural gas) has been demonstrated. CEC is supporting the demonstration of a low-swirl burner based 65 kW microturbine operating on digester gas. For conventional DLN high-swirl burners, the development of staging strategy holds promise for fuel-interchangeable operation. In development and adaptation of these technologies to fuel-interchangeable systems, the technical issues will be to find passive means to mitigate blow-out, flash back, while maintaining a clean and stable flame. Other issues concern with engineering of a fuel injection and premixing system optimized for different fuel properties. For these systems to have maximum impact on renewable fuel penetration, the key challenge is to make them compatible in size, shape and functionality with most existing system platforms.

Justification

Renewable gaseous fuels from waste water treatment plants, agricultural biomass, and landfills are often released into the atmosphere because they require special and costlier equipment to utilize on site, and their supply can be intermittent. Cost-competitive and reliable gas-fuel interchangeable combustion systems, i.e. ones that operate efficiently and ultra-clean on renewable fuels, natural gas and their blends, will eliminate releasing or flaring by providing a reliable platform to convert waste gases to energy, and ensuring a stable energy supply because natural gas can be used as a makeup or backup fuel. This initiative will create an excellent opportunity for California to accelerate renewable gas fuel penetration through on site or local utilization. This will be a significant component in helping the State reach our 33% renewable energy goal for 2020. Additionally, increasing fuel-interchangeability with greater turndown capability saves energy by allowing combustion systems to operate at maximum efficiencies at different load points.

This strategy will provide natural gas ratepayer benefits through

- A market enabler for broader and direct utilization of renewable gaseous fuels to impact on all economic sectors that utilize natural gas combustion systems.
- Fuel-interchangeable combustion systems will have maximum technology potential for commercial to large industrial heaters and power generators.
- Fuel interchangeable combustion systems that are compatible in size, foot-print and functionality with current heating and power equipment have maximum market potential for retrofits and new installations.
- The technical potential of available renewable biomass in California is estimated to be 40M tones in 2020 [1,2]. Utilizing all the biomass will offset 50M tones of CO_2 from fossil fuels [3]. The economic value in terms of carbon offset credit of $15 - $20 /ton CO_2 approaches $1B

Ratepayer Benefit

x Promote greater reliability

x Lower costs

x Increased safety

☐ Social benefits

x GHG emissions mitigation at the lowest possible cost

x Economic development

[1] Williams, R. B., B. M. Jenkins, and S. Kaffka. "An Assessment of Biomass Resources in California, 2007." *PIER Collaborative Report. California Energy Commission, Sacramento* (2008).

[2] http://www.resources.ca.gov/docs/2012_Bioenergy_Action_Plan.pdf

[3] http://www.epa.gov/climateleadership/documents/emission-factors.pdf

Name of Initiative

58. Regional Clean Energy Integration Study

Issues or Barriers
A current barrier is the lack of understanding of how natural gas futures will impact the development of both a “smart” gas grid and “smart” electric grid. Understanding future natural gas scenarios in California is necessary to reduce risk and lower energy costs, as well as promote energy planning and understanding of operational impacts of large renewable energy penetrations and natural gas use in both power generation and transportation futures.

How will this technology or strategy help address the issue/issues?
Natural gas scenarios with high renewable energy, CHP, and natural gas transportation (including biogas) penetration are poorly understood in terms of their cumulative gas demand, gas pipeline capacities, gas storage, and future electric and natural gas vehicle usage. This study will reduce risk and uncertainty to both electric utilities and gas companies by bounding the operational impacts and furthering future energy planning across energy sectors.

Initiative Description and Purpose
This study will examine the natural gas/renewable energy nexus and look at scenario analysis in the 5-20 year timeframe with operational impacts and planning implications for both the gas grid and the electric grid. This will focus on natural gas scenarios that include gas supplying the ancillary services (regulation and ramping) required for large renewable energy penetrations, coupled with a high natural gas scenario for heavy duty vehicles and a high combined heat and power (CHP) build out. The study will also factor in potential natural gas demand reduction through expanded use of solar thermal in the residential, commercial, industrial, and power generation applications. This study will address the impacts on natural gas supply and transmission and address issues that can only be addressed by including the synergistic effects from both the electricity and transportation sectors. The impacts from the scenario analysis on gas supply and regional pipeline capacity will be quantified and the potential for hybrid generation and distributed generation gas technologies (as part of the future CHP scenarios) will be evaluated using energy integration tools and models.

Stakeholders
Results of the study would benefit energy utilities, regulatory stakeholders, and policymakers in understanding the implications of expanded roles for renewable energy and natural gas in power generation (including CHP) and transportation. Understanding and insights would help to optimize investment in energy delivery infrastructure for both electric and natural gas utilities.

Background and the State-of-the-Art
Several studies have been done to quantify future carbon emission reductions with natural gas scenarios (LBL 2005, ICF 2005, CEC 2008, EEC 2010) for both the electricity and transportation sectors in California. However, these studies have not looked at the cumulative operational and long-term planning impacts on these sectors. Renewable energy integration studies using production cost models and related modeling tools have shown the value of scenario modeling to understanding key operational and planning issues, including detailed emission and cost impacts on conventional gas generation ramping and emissions from high renewable penetrations (NREL 2012). This study would build on the success to date of the current electricity and transportation models to examine the combined operation and planning impacts of future low carbon natural gas scenarios in California. The modeling tool developed and the results would extend the understanding of energy integration issues for natural gas in both the electricity and transportation sectors in California.

Justification
Ratepayer benefits can accrue from this study by enabling cost-efficient investment in natural gas infrastructure to meet future needs for end use markets (residential, commercial, industrial, power generation, and vehicles). An expanded role for natural gas in providing "firming" support or highly dynamic renewable power sources (e.g., wind and solar) may place stress on natural gas pipeline and storage capacity in California. Interoperability concerns that link electricity and natural gas supply systems and customers can raise reliability concerns that need to be mitigated.

Ratepayer Benefit
- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- ☐ Economic development

Name of Initiative

59. Scalable, Above-Ground Compressed Air Energy Storage (CAES) of Renewable Energy

Issues or Barriers

Utilities face the challenge of integrating intermittent renewable resources, including solar and wind, into their systems. Batteries have limitations for such applications in terms of limited life cycles, size, and eventual disposal costs. CAES represents a viable alternative to store renewable energy. However, this technology has traditionally required unique, site-specific geologic conditions. This geologic aspect is limiting market adoption of this clean energy technology. Further, limited work has been done to investigate above-ground, man-made pipe-based storage for CAES applications.

Initiative Description and Purpose

We propose to develop a conceptual design and associated economics of a 30 Megawatt (MW), 240 Megawatt-hour (MWh) per day natural gas fired CAES facility using man-made, above-ground storage that: 1) can be used by utilities in communities and industrial parks throughout their system or used on their existing plant sites; 2) would enable integration of intermittent renewables, making them firm, dispatchable power; 3) would be repeatable at multiple locations, and 4) would allow for strategic islanding of the electrical grid following a major transmission outage using local urban renewable resources..

We propose to accomplish the following:

- Define a CAES facility with above-ground air storage that would absorb or supplement, as may be required to make intermittent renewables firm, dispatchable resources by providing up to 240 MWh per day (1680 MWh/week, 87,360 MWh/year) of firming energy.
- Provide high conversion of natural gas to electricity for lower natural gas consumption and lower emissions.
- Investigate advanced techniques for cost reduction and efficiency improvement, compared to traditional methods:
    - Air stored at 1500 psig. Options of 800 psi pressure utilization or 1500 psi with sliding pressure to 500 psi. More of the stored air is utilized with smaller volume storage.
    - Investigate expander(s) flexibility to handle three different pressures: 1500, 800, and 500 psi. This is a more complex option, but enables the lowest storage volume; thereby reducing the cost of the storage reservoir.
    - Investigate lower air consumption by adding humidification to air for same capacity as dry concept.
    - Investigate water recovery from expander exhaust for improved efficiency.

- Improve small systems to compete with equivalent larger CAES systems in terms of performance and $/kW cost. Compare small CAES concept vs. large battery capacity of equivalent MWh.
- Perform dispatch modeling--renewable power inflow at variable rates, etc.
- Compare higher cost of site-installed pipe storage labor with factory-fabricated pressure vessels for lower on-site labor and construction costs.
- Consider the application of such natural gas fired CAES at critical substations in Los Angeles area to better withstand transmission outages.

Stakeholders
Burbank Water & Power (BWP) would support this initiative. The development would be designed using the actual conditions and needs of BWP, but would be designed to enable repeatable application by multiple municipal utilities at multiple locations.

Background and the State-of-the-Art
Work is underway in California, Ohio, and Texas to develop large-scale CAES facilities; in part for renewables integration. These efforts are of relatively large scale (135 MW or more), site geology-dependent projects. They depend upon underground geology suitable for energy storage; such sites are difficult to find We propose a proof of concept that does not have such geological requirements but is instead designed with the specific requirements to response to the firming requirements of intermittent renewable energy resources and the dynamic response required for transmission outage events where such facilities can be installed in urban areas where needed.

Justification
This technology and strategy will provide renewables integration and system operational benefits through the efficient use of natural gas for electric generation during peak load periods. The CAES alternative will consume only about one-half the natural gas per MWh of generation compared to a conventional, single-cycle combustion turbine peaking plant.

- ***Sector size and energy use****.* This technology will have the greatest impact in urban or industrial park settings.
- ***Maximum technology potential***. Replace all existing small steam units and support energy storage of two-thirds of solar and wind capacity. This technology would be intended as a replacement for older generating facilities as they are retired.
- ***Maximum market potential***. The maximum potential would be to replace all existing small steam generation units and backup up to two-thirds of intermittent renewable resources with this technology and provide energy storage for utilities by locating the above-ground CAES at major substation sites and near power plants. This type of storage has also the potential to replace existing or provide new backup generators at airports, hospitals, military installations, refineries, and any enterprise that has a critical need to maintain power supplies.

Ratepayer Benefit

- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

60. Hybrid solar thermal/gas cooling solutions

Issues or Barriers
Heat activated absorption chiller technologies are readily available in the market today but the cost of purchasing and installing an absorption chiller remains high as compared to a comparable electric chiller and electric chiller systems operate less efficiently when the sun is very hot. However, a thermally fueled absorption chiller cooling system (with both solar fuel and natural gas back-up) functions best during the hottest parts of the day because its fuel (sunlight) is most abundant. Currently, the scale for such systems is small and larger systems are needed to show cost-effectiveness. The CSI has proposed to implement incentives for these renewable air conditioning systems but has yet to do so because the stake holders cannot agree on the manner in which energy savings should be quantified.

Initiative Description and Purpose
Develop a cost effective, hybrid solution that integrates the use of natural gas and other associated components in order to provide continuous heating and cooling capability. The study should include:

1) Monitored commercial operation and integration of a double effect absorption system with MicroCSP collectors;
2) Optimal MicroCSP array and absorption chiller performance metrics and conditions;
3) Economic analysis of system installation and electricity savings; and
4) Integration of absorption system with existing electric driven cooling systems.
5) Establishment of industry standards for monitoring and quantifying system performance
6) Development of thermal storage technologies to reduce space requirement, increase storage time and reduce costs

Stakeholders
DOE, CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Solar thermal technologies have traditionally been applied in residential markets for pool heating and in utility scale electric generation plants. Recently, several new concentrated solar thermal collector manufacturers' have entered the market with technologies that can be more easily applied to commercial and industrial facilities. Companies like Sopogy, Cogenra and Chromasun all produce collectors that can be used effectively in commercial and industrial applications including hybrid solar cooling systems. New technology systems such as Solar Cooling need scaling and initial demonstration funding in order to take hold in the market. Once sites become available

and economic data for system paypack is provided, these systems will become more commercially viable.

Justification

- Renewable Energy
- Greenhouse gas reduction
- NOx emission reduction
- Energy Efficiency
- 30-40% of electric peak load demand reduction
- Potential to increase green jobs in CA

Ratepayer Benefit

x Promote greater reliability

x Lower costs

☐ Increased safety

x Societal benefits

x GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative

61. Renewable – Solar Thermal Process Heat

Issues or Barriers
Production of heat for industrial process utilizing solar thermal technologies can be done but is inhibited by the high costs to implement the technology. Higher temperature solar thermal technologies already exist but given the current price of natural gas, such installations remain too expensive to implement, especially if thermal energy storage is considered. The CSI has proposed to implement incentives for these technologies but has yet to do so because the stake holders cannot agree on the manner in which energy savings should be quantified.

Initiative Description and Purpose
Development of industry standards and monitoring technologies that can be used to easily quantify energy absorbed, energy saved and greenhouse gas and NOx emissions avoided. Development of thermal storage technologies that reduces equipment space requirements, increases storage times and reduces of cost to implement.

Stakeholders
DOE, CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
Solar thermal technologies have traditionally been applied in residential markets for pool heating and in utility scale electric generation plants. Recently, several new concentrated solar thermal collector manufacturers' have entered the market with technologies that can be more easily applied to commercial and industrial facilities. Companies like Sopogy, Cogenra and Chromasun all produce collectors that can be used effectively in commercial and industrial applications.

Justification
- Renewable Energy
- Greenhouse gas reduction
- NOx emission reduction
- Energy Efficiency
- 30-50% reduction in commercial/industrial gas usage

Ratepayer Benefit
x Promote greater reliability

x Lower costs

☐ Increased safety

x Societal benefits

x GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative

62. Renewable Natural Gas Production and Conditioning FEED Studies

Issues or Barriers

Renewable natural gas (RNG) has market advantages over other forms of renewable energy relate to the fact that RNG can readily use California's mature natural gas storage and distribution infrastructure. This allows RNG to be stored and transported to customers throughout the state.

However, RNG typically costs more to produce because, in order to meet distribution quality standards RNG must be separated from other biogenic gases and contaminates such as CO2, H2S, N2 and silicon compounds. Another significant issue in the deployment of RNG is finding sufficient feedstock and commercially viable technology. Anaerobic digestion is a mature technology but finding sufficient feedstock is difficult. Gasification systems scaled to be compatible with biomass availability (i.e., 250 to 500 tons per day) are not commercially proven.

Initiative Description and Purpose

The goal of this initiative is to identify the best emerging lower-cost technologies and prepare front-end engineering (FEED) studies for three pilot plants to deploy the these technologies:

1. Upgrading of biogas from an existing anaerobic digester to pipeline quality RNG
2. Conversion of solid biomass to RNG, and
3. Recycling CO2 into RNG.

These FEED studies will enable the fund raising required to build and operate these pilot demonstrations.

Stakeholders

RNG Customers:

- Electric utilities
- Natural gas vehicle fleets
- Light duty NGV owners

RNG Producers:

- Wastewater treatment plants
- Landfills
- Forage grass producers/exporters
- Cattle finishing operations
- Agricultural processing industries

Background and the State-of-the-Art

Biogas Upgrade: There are currently four basic technologies for conversion of biogas (i.e., methane and carbon dioxide) into natural gas.

- Pressure swing absorption: This technology has been successfully proven by SoCalGas at the Hale Avenue Resource Recovery Facility in Escondido, CA. This technology can remove nitrogen and oxygen after initial processing to remove siloxanes and hydrogen sulfide. This technology can recover 90% of the methane.
- Amine scrubbing: this technology is used throughout the world to purify conventional natural gas and in Europe it is used to upgrade agricultural biogas to pipeline quality standards. It has challenges with nitrogen and oxygen than can be present in biogas. The technology also uses significant amount of heat to run the process. This technology can recovery > 95% of the methane.
- Water scrubbing: this technology is being deployed in Europe. It uses less energy than amine scrubbing. It can also remove siloxanes and hydrogen sulfide without addition process steps. It cannot remove oxygen or nitrogen. This technology can recover > 95% of the methane.
- Membranes: This technology has been used for landfill gas upgrading. It does not remove nitrogen or oxygen. This technology is typically deployed with a pressure swing absorption polishing step. This process can recover > 90% of the methane.

Solid Biomass Conversion: This technology uses gasification to convert solid biomass into carbon monoxide and hydrogen (i.e., syngas). The syngas can then be catalytically transformed into RNG. The processes necessary for gasification and RNG production are well known. An economically viable, small scale gasifier (i.e., 250 to 500 tons per day) which can produce high quality syngas is not available. Companies such as Synterra, Frontline Bioenergy, PrimEnergy are nearing commercial scale.

Recycling CO2: Several companies in the biofuels space are developing photosynthetic organisms that can produce and secrete sugars or oils. For example, Proterro, biotechnology start-up, has developed a blue-green algae that converts carbon dioxide and sunlight to sucrose and secrete the sucrose. The sucrose can then be fed into an existing anaerobic digester for conversion into RNG. This process appears to have a significant increase in capture of solar energy compared to commercially available photovoltaic panels. Proterro has proven their ability to produce sucrose at the pilot scale. The commercial scale production of sucrose has not been shown.

Justification

The goal of this effort is to help develop an economically viable RNG industry in California using all available feedstock found in the State of California by preparing FEED studies for emerging lower cost technologies in three areas, that allows RNG production from liquid feedstock (anaerobic digestion with biogas upgrade), solid biomass and carbon dioxide/solar energy, we seek to promote an industry to could meet more that 10% of California's energy needs.

Ratepayer Benefit

x Promote greater reliability

x Lower costs

☐ Increased safety

x Societal benefits

x GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative

63. Natural Gas Production from Solar Thermal Catalytic Reformation of CO2 and H2O

Issues or Barriers
Solar-chemical technologies currently lag behind solar-electric and solar thermal technologies in process efficiency due to a lack of funding allocated to solar-chemical RD&D and the relatively low price of conventional natural gas.

Initiative Description and Purpose
Our group is supporting the erection of a large concentrating solar dish at San Diego State Brawley campus. The purpose of this project is to demonstrate large scale hydrogen and methane production from water and carbon dioxide, respectively.

Stakeholders
RNG Customers:

- Electric utilities
- Natural gas vehicle fleets
- Light duty NGV owners

CO2 Producers:

- Food processors
- Breweries
- Wastewater treatment plants
- Landfills
- Electric power plants

Background and the State-of-the-Art
Recent laboratory-scale demonstrations have shown that solar chemical technologies have the potential to covert solar energy into gaseous and liquid fuels and other hydrocarbons that can be stored and transported more efficiently than electrical and thermal energy. For example, using a solar cavity-receiver reactor, Caltech researchers "combined the oxygen uptake and release capacity of cerium oxide and facile catalysis at elevated temperatures to thermochemically dissociate CO2 and H2O, yielding CO and H2, respectively. Stable and rapid generation of fuel was demonstrated over 500 cycles. Solar-to-fuel efficiencies of 0.7 to 0.8% were achieved and shown to be largely limited by the system scale and design rather than by chemistry."

Justification
The goal of this effort is to demonstrate solar chemical H2 and CH4 production at a larger, more efficient scale.

Ratepayer Benefit

- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- ☐ Economic development

Name of Initiative

64. Improved Low Emissions Fuel Flexible Generation for Biomass Derived Fuels

Issues or Barriers

Treatment of waste steams through landfills or water reclamation plants can produce low carbon fuels that are comprised mainly of CO2 and methane. In addition, these waste streams as well as biomass waste can be gasified to produce a mix of hydrogen and carbon monoxide. The degree to which these fuels can be used via a centralized distributions system (e.g. existing natural gas pipelines) is debatable as the low power density would lead to impact associated with transport of material. Alternatively, this fuel can be used locally (e.g., distributed generation). To be successful, the generation approach should be able to operate with low emissions on gasifier derived fuels as well as natural gas as a supplement or backup. The challenge with this is the high reactively of hydrogen. Current low emissions combustion systems tend to operate premixed to minimize NOx forming temperatures. With hydrogen, the possibility of flashback or change in the location of heat release can lead to operability issues. Hence understanding of how mixtures of natural gas and gasification derived fuels impact combustion system performance and emissions.

Initiative Description and Purpose

The proposed initiative would apply/develop fuel interchange criteria or methodologies to predict the impact of fuel variability on various combustion systems and to help evolve strategies to improve fuel flexibility of such systems.

Stakeholders

Combustion system OEMs that provide gas turbines, reciprocating engines, boiler burners, end users, agricultural entities, and air quality agencies.

Background and the State-of-the-Art

The CEC has sponsored research involved at development of gasification technology as well as low emissions prime mover technology. However, only limited efforts have been carried out to improve fuel flexibility of power generation that would result from coupling these two technologies. The CEC has also sponsored research on development of fuel interchangeability that has emphasized natural gas and higher hydrocarbons. Some work has also included hydrogen natural gas mixtures. This has led to data and interchange methodologies than can, in principle, be used to help understand how combustion system performance is impacted by variation in fuel composition. The Department of Energy has also funded research looking at operation of advanced gas turbines on high hydrogen content fuels. This research has also led to the development of data associated with combustion characteristics of high hydrogen and pure hydrogen fuels. It has also funded work integrating a gas turbine with a gasifier. This project fell short of full demonstration due to business challenges associated with the gasifier provider.

Justification
Improved fuel flexible, low emission power generation can be used to significantly reduce the carbon signature associated use of fuels. If successful, facilitation of this market sector could lead to high efficiency local power generation not unlike the increasing deployment of distributed generation at waste water treatment plants. It will also address an increasing need to reduce biomass disposal in landfills. It is estimated that biomass could provide up to 11% of the California power needs. In addition, biomass can also be derived from fire prevention measures associated with proper clearing procedures. This approach could also have an impact on job creation in areas rich in biomass associated with plant installation and operations.

Ratepayer Benefit
- x Promote greater reliability
- x Lower costs
- x Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

65. Low Cost Fuel Flexible DG/CHP for use with variable Natural Gas, Shale Gas and Biogas Blends

Issues or Barriers
Distributed Generation/Combined Heat and Power is expected to be a major component of the future California AB32 implementation plan. However, performance of current DG/CHP systems can be compromised with variations in natural gas fuel properties that may result from introduction of “fracked” shale gas, bio-gas injection, or even hydrogen injection strategies to offset use of existing natural gas reserves. DG/CHP systems that are unable to cope with fuel variations will, at a minimum, not operate as intended (reduced efficiency, increased pollutant and CO2 emissions) and at worse, fail removing this resource from the power mix.

Initiative Description and Purpose
Development of fuel flexible DG/CHP prime mover will provide crucial tolerance to fuel composition variations that may be seen by a system. This initiative would directly address the adaptation of a rotary engine for use in DG/CHP applications.

Stakeholders
Gas Suppliers, Rotary Engine suppliers (Mazda)

Background and the State-of-the-Art
Demonstration units of a rotary engine DG/CHP system have been and continue to operate at Mazda Japan. These engines have demonstrated all of the attributes of rotary engines (low noise, vibration, small package size, extreme longevity). In vehicle applications, the engines have demonstrated diverse fuel flexibility, the same engine operating on both gasoline and hydrogen (about as diverse in fuel properties as can be imagined). Programs to demonstrate the fuel flexibility in DG/CHP applications have not been undertaken to date.

Justification
The adoption of DG/CHP in the overall California energy plan, and the attributes therein of reduced CO2 emissions, reduced overall fuel consumption through the capture of otherwise wasted heat, and improvements to grid reliability offered by DG/CHP are fully and further supported by the development of a fuel flexible DG/CHP system. Furthermore, the specific development of a rotary engine based system offers benefits of reduced up front capital costs and operation and maintenance costs due to the commonality to mass production of the prime mover and supporting component for automobile applications. The expected life of a rotary engine is approximately 5 times that of a conventional reciprocating engine due to reduced number of moving parts; the expected life is about half that of a turbine engine but, with a replacement cost of 1/10th that of a turbine, the overall life time cost for electric power production is about half that of a turbine engine of comparable size.

Ratepayer Benefit

- x Promote greater reliability
- x Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

66. Partial refueling of combined cycles with biomass syngas

Issues or Barriers

Energy planners are moving away from large centralized biomass based power plants to a more decentralized concept of supply which fits nicely with the nature of biomass resources. Due to its low energy density, transportation of biomass collected from various locations over long distances to a central plant makes it economically prohibitive to compete with well-established energy carriers such as coal, oil and natural gas. Furthermore, due to the seasonal variation in the feedstock availability and due to the smaller size of decentralized biomass gasification facilities, the construction of a new pipeline dedicated to transportation of the syngas over long distances would not be an economically attractive option. Thus, either (i) the biomass facility has to be located in close proximity to the feedstock as well as to the existing combined cycle plant to be refueled, or (ii) produce a syngas that is compatible for injection into an existing natural gas pipeline that is in close proximity to the biomass facility. During seasons of low biomass feedstock availability, the existing combined cycle plant would have to increase its natural gas usage (i.e., approach its original consumption rate) to off-set the decrease in the biomass derived syngas supply.

Initiative Description and Purpose

The main objective of the research study described here is to advance the mixed use and hybridization of renewable energy technologies in order to synergistically maximize plant output while minimizing environmental impacts. These objectives can be realized by systems studies as a necessary first step. These studies would evaluate the technoeconomic feasibility of constructing biomass gasification facilities to displace at least a portion of the natural gas (i) required by existing combined cycle plants and (ii) in existing natural gas pipelines. The biomass derived syngas which is considered “CO2 neutral” would thus displace a portion of the natural gas used by the existing users.

Stakeholders

This research study should have a direct impact on improving the quality of life for California's citizens since it aims at developing environmentally sound, safe, reliable and affordable energy services and products to assist individuals, communities and utilities across the state in meeting renewable energy and sustainability goals. Thus, it is expected that both gas and electric utilities would be major stake holders since it addresses the goals of the state in reducing greenhouse gas emissions.

Background and the State-of-the-Art

Option 1. The study approach would consist of identifying the suitable refueling scenarios of natural gas fired combined cycle plants within the state of California with syngas derived from biomass gasification by (i) identifying potential candidate plants that meet the criteria of being located in the proximity of biomass resources, (ii) identifying and evaluating suitable technologies for biomass conversion to a **clean**

syngas (i.e., contaminants including H2S, COS, other sulfur compounds, NH3, HCN, HCl, any tars/oils, particulates, carbonyls, dioxins/furans although not expected to form under reducing conditions removed) ,and the refueling of existing combined cycles, (iii) developing the overall plant performances (biomass conversion facility as well as the refueled combined cycle plant), (iv) developing the overall environmental signature including the expected impact on NOx emissions from the refueled plant (it is recommended that a separate research program be funded to quantify the detailed impacts on emissions) and (v) developing the rough order of magnitude capital and operating expenditure requirements for a selected number of combined cycle power plants.

Option 2. The study approach would consist of identifying the suitable scenarios of natural gas pipelines within the state of California with syngas derived from biomass gasification by (i) identifying potential candidate pipelines that meet the criteria of being located in the proximity of biomass resources, (ii) identifying and evaluating suitable technologies for biomass conversion to a **clean syngas** (a CO free syngas may be desirable), (iii) assessing the biomass plant performance as well as impacts on the pipeline and end users while taking into account the acceptable variability in the Modified Wobbe Index, (iv) developing the overall environmental signature including the expected impact on NOx emissions at the end users (it is recommended that a separate research program be funded to quantify the detailed impacts on emissions) and (v) developing the rough order of magnitude capital and operating expenditure requirements for a selected number of pipelines and end user scenarios.

The biomass resources to be considered are:

- Agricultural crops
- Wood wastes and residues
- Animal wastes
- Municipal wastes
- Aquatic plants.

Justification

This utility scale renewable energy research study would target at filling knowledge gaps and technology needs to deploy and integrate utility scale renewable energy in a stable, secure, and environmentally friendly manner. In addition to focusing on systems engineering, it would develop the necessary data; identify technologies and tools for planning and operating large renewable energy power plants that work with state, regional, and local pipeline and transmission resources.

The objectives of this biomass research study would support increased deployment and integration of biomass energy in communities throughout California and at the utility scale. This research would be an important component in the effort to reduce greenhouse gas emissions and move towards California's goal of reaching an 80% reduction of greenhouse gas emissions below the 1990 levels by 2050. Use of biomass

waste generated by communities will also reduce the waste disposal requirements and landfill gas emissions, another set of environmental benefits.

Ratepayer Benefit

- ☐ Promote greater reliability
- ☐ Lower costs
- ☐ Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative

67. Sythetic gas from renewable

Jesselyn

I own a company that has been doing research with the University of California at Riverside. The process is called steam hydrogasification and is a therma-chemical process that is done in the presents of Hydrogen rather than oxygen.

According to DOE, it has a 24% less capital requirement and is 12 to 15% higher efficiency that POX. It is also agnostic as to the feedstock. It operates at a much less teperature than POX and therefore less expensive to build. The process makes a lot of Hydrogen and or CH4 and can be made to make different ratio's of CO and H2. It likes moisture in the feedstock, so it is well suited for biomass as well as lowgrade coals such as lignite. We were granted an SBIR to make Methane and those tests went very well. It is our opinion that we can make methane much cheaper that other processes due to the reasons stated above. We would like to know if there is any fundig available for further research. We are currently getting $2.4 million from DOE to build a 5tpd pilot plant in Utah but are short at least 3 million dollars. We think that this could be a game changer due to the lower costs and operating conditions. We have tested most type of carbon from food waste to woody waste to manure, with good results. Please let me know how you would like for me to proceed.

Thanks for your time and consideration.

Natural Gas – Proposed Research Initiative

Program Area:

Natural Gas Infrastructure.

Conduct research that focuses on enhancing transmission and distribution capabilities of the natural gas system, and enhancing the safety and integrity of the natural gas pipeline.

Name of Initiative/Topic:

68. Opportunities to Deliver Biomethane into California Natural Gas pipeline system or dedicated pipelines.

Issues or Barriers

California biomethane developers recently (end of prior legislative session) got help via AB 1900, which creates a path to determine the standards to which their gas must be processed so that the gas utilities can accept their gas. But processing is only part of the question. The other part of the question is whether the landfills and waste water treatment plants big enough to produce biomethane are located relative to the gas system (or a power plant that could take the gas via dedicated pipeline). For some landfills the nearest gas pipeline may still be too far to make a project economic; for others, the logical gas system interconnection may be into a pipe that is constrained during all or parts of a day or days. Interconnection studies by the gas utilities would typically be pursued one by one at developer request. By screening landfills on a batch basis we could short-cut the time to develop projects by identifying the most promising landfills for interconnection studies while the standards work is underway on a parallel path.

Initiative Description and Purpose

The initiative would identify the locations of landfills (and waste water treatment plants) in California large enough to produce biomethane and assess their distance to power plants that could burn the gas and/or proximity to natural gas lines that could potentially accept the gas into the California natural gas pipeline system if the gas met appropriate standards being developed pursuant to AB 1900 (Gatto).

Stakeholders

Theoretical stakeholders include California biomethane developers and power plants that seek to burn biomethane to meet their RPS requirements. Several municipal and investor-owned utilities have purchased biomethane from out-of-state and would undoubtedly support efforts to encourage building an in-state industry.

Background and the State-of-the-Art

AB 1900 (Gatto), passed in 2012, provides that several state agencies must work together to find solutions to allow California-produced biomethane a way into the California natural gas system. Aside from the question of processing the biomethane so that the system can accept the gas, interconnection requests would typically be looked at on a case-by-case basis. By mapping the location of landfills large enough to produce biomethane relative to power plants and the gas pipeline system, we can jump start that process and help producers as well as the gas utilities focus on landfills that we can most easily incorporate into the gas system. This will also enable California to better estimate biomethane potential and take practical steps to make it accessible.

Justification
This initiative will provide hard information about where California landfills are located relative to power plants that can burn the gas versus the potential interconnects to inject it into the California natural gas system.

Ratepayer Benefit (Check one or more.)
x Promote greater reliability
x Lower costs
x Increased safety
x Societal benefits
x GHG emissions mitigation at the lowest possible cost
x Economic development

Name of Initiative/Topic:

69. Renewable Intermittency Impact on Natural Gas System

Issues or Barriers

One of the most often talked about issues in reaching California's goal of serving at least 33% of our electricity load with renewables is integration and backing them up with gas-fired generation. Yet virtually none of that discussion takes into account how California's gas infrastructure actually works or recognizes that the utility tariffs require ratable hourly deliveries and shippers to match deliveries with their usage – for a reason. This study aims at understanding what the limits might be on our ability to use natural gas delivery infrastructure in this way and exploring options to address those limits.

Initiative Description and Purpose

The analysis would look at hourly gas ramps under normal conditions versus the potential ramps to backup renewables. If the expected hourly gas ramps are larger than what we experience now, then look at which power plants would fire up or down and, with the gas utilities, at whether the ramp up/down could violate any pressure limits or inventory limits on the pipes that serve those plants. What assets are the gas utilities using to manage hourly load changes now and will they assets and current rules continue to be adequate? Last, the analysis would consider whether the renewables back-up causes any greater pressure cycling within the pipelines than they experience now and whether that could cause a safety concern?

Stakeholders

Confirmed Supporting Stakeholders include:
The California Energy Commission's Electricity Supply and Analysis Division
California Independent System Operator. Additional entities that should benefit from and/or participate in the initiative include the gas-fired generators who will be relied upon to fire up and down to follow intermittent renewable and the gas utilities who may have more difficulty balancing their systems.

Background and the State-of-the-Art

Prior analysis on this issue performed under PIER focused on whether the gas system had enough spare capacity on a daily basis to deliver the incremental gas supply needed to replace renewables generation – and the answer was that yes, it did [1]. The next issue posed by using gas to back up renewables is how a gas system that itself must remain in balance reacts to the sudden and large hourly ramp that renewables will impose. Based on CAISO analysis (see, for example, "Operational Challenges to Integrate 33% Renewable Generation" presented by Dr. Shucheng Liu, August 24, 2012) and Aspen supplemental calculations, these ramps could be 20% of system gas demand in a given hour (and more on a low demand day). The gas system already seems to be experiencing more and more days with operational flow orders; we have also seen mention in the CPUC's Investigation into the 2010 explosion at San Bruno

that daily pressure cycling may cause more fatigue to natural gas than previously thought.
The biggest difficulty with some of the analysis that needs to be undertaken is that only the gas utilities possess some of the data needed (such as hourly flows on their systems) and only the gas utilities know the nuances of how they can apply the tools available to them to manage sudden hourly gas ramp. By performing this analysis under a public research program, we hope to achieve access to data and personnel and approach the analysis and findings independently, yet collaboratively.

Justification
This initiative topic will:

- enable ratepayers and policymakers to understand any limits on the gas system's ability to deliver gas to support fast ramp renewables backup;
- help the gas utilities determine what new facilities they may need to add or tariff provisions they may need to change;
- help the CAISO determine what costs it should expect generators to incur;
- help generators and CAISO better even better appreciate gas system integrity;
- help CEC and CPUC understand if they need to adopt any different policies to help the gas system respond to the ramp requirements; and
- help the electricity industry and stakeholders understand potential additional costs of renewables integration.

Ratepayer Benefit (Check one or more.)
X Promote greater reliability
X Lower costs
x Increased safety
x Societal benefits
GHG emissions mitigation at the lowest possible cost
Economic development

1 See
http://www.energy.ca.gov/2009publications/CEC-500-2009-083/CEC-500-2009-083.PDF

Name of Initiative/Topic:

70. Miniature methane sensor network

Issues or Barriers

Our company has developed miniature, open-path sensors with portability (100's g) and sensitivity (10's ppb) to detect methane at levels appropriate for both public safety and greenhouse gas monitoring. Our company has the robotics capability to apply this sensor on miniature aerial robotic platforms that greatly increase monitoring capability. Key barriers are ruggedization and repeatability - we envision this to be all weather and applicable in low (2 ppm) and high (few %) gas environments. A barrier for implementation of robotic aerial platforms is reliable, safe operation close to ground and structures. A key issue is integrating this sensor into a larger monitoring network that provides real-time, accurate information to stakeholders and makes best use of methane and meteorological data as well as available resources.

Initiative Description and Purpose

We propose to implement these sensors in a regional (e.g. citywide) network driven by concentration/meteorology measurements and adaptive decision-making. Sensors will be both human-carried and integrated in small-UAVs (vertical take-off and landing and fixed-wing). Our prototype sensors need to be ruggedized to guarantee stable measurements under all weather conditions. Safe operation of small aerial platforms at low altitude in cluttered environments requires on-board autonomous navigation to avoid collisions and perform simple maneuvers such as autonomous re-powering. Operation of a multi-agent sensor network involves automated control for optimal sensor placement and to react effectively to gas leaks. Network development can be done employing human-carried devices integrated into a larger, decision-making system. Our company will develop the decision and analysis tools that utilize atmospheric dispersion models to define paths to reach methane sources and quantify flux. These tools enable future autonomous monitoring and response capability. Our company has extensive knowledge in all these areas, leveraging technologies originally developed for planetary robots and spacecraft operation.

Stakeholders

- Energy industry (utilities, gas operators)
- State of California Air Resources Board

Background and the State-of-the-Art

Current state-of-the-art commercial gas sensors with 10s ppb methane sensitivity cannot be hand-carried or implemented on small-UAVs. The autonomous, hazard-avoidance, and navigation necessary for small-UAVs in crowded environments needs to be fine-tuned for terrestrial applications. The adaptive, multi-agent decision-making network fed by real-time meteorology and gas concentration data must be built. We

propose to develop all of the above to build a regional network that monitors natural gas emissions in real-time and alerts stakeholders of anomalous events.

Justification

- Public safety - Leak surveys are a key component of the safety plan of gas operators
- and Local Distribution Companies. Frequent and effective leak detections are
- instrumental in preventing incidents and reducing emissions of methane in the
- atmosphere.
- Reduced cost: In volume, miniature methane sensors are anticipated to cost 5-10x less than current CRDS-based sensors.
- The science and engineering developments used for this terrestrial application
- strengthens NASA's ability to conduct planetary science missions. For example, the
- hazard avoidance developed in a complicated environment may be applicable to
- maneuvering a planetary rover around rocks.

Ratepayer Benefit (Check one or more.)

☒ Promote greater reliability

☒ Lower costs

☒ Increased safety

☒ Societal benefits

☒ GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative:

71. Disbonded Coating of Steel Pipe

Issues or Barriers
There is currently no technology, other than exploratory excavation, that can detect a disbonded coating on buried steel pipe that could lead to an actual break. A disbonded coating can contain an active corrosion cell that is undetectable until serious damage has occurred to the pipe wall. There is no exterior method that can reliably detect disbanded coating at this time.

Initiative Description and Purpose
A technique that can detect this condition from above ground is highly desirable in that it can be quickly applied and less expensive than those requiring excavation.

Stakeholders
Gas Transmission and Distribution companies.

Background and the State-of-the-Art
Another company completed a proof-of-concept on a project named “Phase Sensitive Method to Detect Pipe Coating Disbondments” under their Sustained Membership Program sponsorship.
Another company is conducting the next phase of this research named “Cathodic Disbondment Detector” under Operations Technology Development sponsorship

Justification
The ability to locate potential corrosion sites before serious metal loss or leaks occur will provide utilities with a tool to improve public safety, improve corrosion mitigation strategies, and improve life-cycle of steel pipelines.

Ratepayer Benefit (Check one or more.)

☐ Promote greater reliability

☒ Lower costs

☒ Increased safety

☐ Societal benefits

☐ GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative:

72. PE Static Charge Mitigation

Issues or Barriers
Internal static charge inside polyethylene (PE) pipe poses a safety hazard to gas company operations. The static charge can dissipate through the pipe wall and cause injury to company employees and/or become an ignition source during PE pipeline repair operations when natural gas is present.

Initiative Description and Purpose
A method to measure the presence of static charge build up inside PE pipe and a cost effective method to neutralize or remove the internal static charge safely is critical to safe utility company operations.

Stakeholders
Gas Distribution companies.

Background and the State-of-the-Art
Another company is currently evaluating the performance of a product called Ionix MA which is claimed to be a static suppression product when injected into the natural gas stream. This company's research will investigate if product affects the long-term performance of PE pipe and fusion joints, and the amount of product required to neutralize the static charge.
Previous related work by GTI: GRI-05/0147 "Static Discharge Failure of PE Pipe" GRI-92/0460 "Electrostatic Discharger System for Polyethylene Pipes in Gas Distribution: Phase I"

Justification
The overall benefits are enhanced safety, improved operations, and reduced costs.

Ratepayer Benefit (Check one or more.)

☐ Promote greater reliability

☒ Lower costs

☒ Increased safety

☐ Societal benefits

☐ GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative:

73. Energy Recovery from High Pressure Reduction

Issues or Barriers
Large compressors are used regularly for gas transmission lines at the state border, booster stations, and in the gas storage fields. Waste heat from the compressors are rejected to atmosphere. In the distribution pipeline systems, as well as the withdraw cycles in the gas storage fields, pressure reducing processes offer energy recovery opportunities, but most of cases are not taken. The challenges are due to load cycling, and site specific conditions preventing a standardized and economical solution. Current regulations also discourage self-generation if there is net output to the power grid.

Initiative Description and Purpose
Research is needed to summarize past study results, characterize the processes, identify and quantify the exact thresholds, and develop innovative and economical solutions. A few demonstration pilot plants are needed. Policy changes are needed to convert the waste energy to electricity and credited to the contributors.

Stakeholders
Customers and ratepayers in all segments will directly and indirectly. Third party generation should be allowed to participate.

Background and the State-of-the-Art
Turbo-expanders can be used to extract useful energy from pressure reducing processes, and convert to electricity. Waste heat from compressor jacket cooling water is of low grade temperature but may be able to be used to generate electricity. These are all existing and mature technologies. The key to success is in system integration and utility policy/law revisions. See reference http://www.ingaa.org/File.aspx?id=9373

Justification
Will provide natural gas ratepayer benefits, with estimated of annual savings/benefits in California: • Commercial (including agricultural), industrial, and residential customers will benefit, affecting 5 BCF/day with 5% savings in natural gas fuel and avoided electric generation, and 5% minimum reduction in associated NOx emissions • Maximum technology potential, if successful – triple of the above estimate
• Maximum market potential, if successful – this emission control technology may be applied and adapted to many industries.

Ratepayer Benefit (Check one or more.)

☐ Promote greater reliability

☒ Lower costs

☒ Increased safety

- ☒ Societal benefits
- ☒ GHG emissions mitigation at the lowest possible cost
- ☒ Economic development

Name of Initiative:

74. Cyber Security for Natural Gas Utilities: Security Information and Event Management (SIEM) Using the DATES System

Issues or Barriers

As industrial control systems (ICS) at natural gas utilities incorporate digital technology, adopt standard protocols and platforms, connect with commodity information technology systems and the Internet, and rely more on wireless communication networks, they become more vulnerable to cyber-threats. The nature of these threats, methods to detect them, and appropriate protocols for addressing them are inadequately understood. New approaches are needed and must be tested before being widely deployed. Our company has developed a prototype system, "DATES," that is specific to a particular SIEM platform. With additional funding, the system could be tailored for other SIEM solutions or event-consuming components and tested in a utility environment. Our framework can be further enhanced with new detection mechanisms for additional control system protocols and with new mechanisms that enable an efficient deployment and maintenance process.

Initiative Description and Purpose

With the emergence of such cyber threats, it becomes imperative to create efficient ICS-specific defense mechanisms that complement traditional enterprise security solutions. While corporate IT systems may be able to shut down during an attack, utilities must continue to provide service. We propose an integrated detection and security information/event management (SIEM) solution that enables asset owners to protect their control systems from cyber attacks at the network, host, and device levels. The SIEM system complements traditional, signature-based detection with multiple detection algorithms including model-based and flow anomaly detection and cross-site attack correlation.

Stakeholders

Utility operators and ratepayers would benefit from this initiative.

Background and the State-of-the-Art

With funding from the United States Department of Energy (Award Number DE-FC26- 07NT43314), SRI International developed and tested a prototype system, called "DATES". The DATES detection and SIEM solution provides succinct and intuitive attack visualization, with attacks prioritized as to their impact on critical cyber assets and network zone crossing. This enhances an asset owner's situational awareness capability beyond simple event detection and log management. The DATES monitoring platform uses multiple algorithms to examine packet headers, including a Snort sensor enhanced with a SCADA-aware rule set, stateful protocol analysis, and a Bayes component. Such a combination of model-based detection with anomaly detection leverages the unique traffic characteristics of energy control systems

to detect zero-day attacks that violate these characteristics. The model-based capability lets the user configure the detection system for valid connection patterns.
DATES detects patterns violating the model-generated specification, such as attacks that alter the connectivity and traffic flows in the users' control systems. The correlation engine comprehends asset criticality, network zones, and alert incident classes, enabling correlation and prioritization of an attack that escalates and crosses to higher criticality zones.
DATES also supports multiple monitoring interfaces, providing the security operator an actionable view of potentially correlated and escalating attacks throughout different parts of the control systems environment. Specific benefits of DATES include:

- Enhances attack detection using protocol analysis and probabilistic (Bayes) detection capabilities
- Provides model-based and anomaly detection for identifying new, zero-day attacks
- Prioritizes and visualizes attacks, particularly attacks that escalate in criticality and/or cross control systems network zone boundaries
- Enhances situational awareness levels compared to simple event detection and log management
- Interfaces passively to the monitored network

Justification
This initiative will provide benefits to ratepayers by advancing the state of the art in cyber security systems that address the unique requirements of the natural gas sector. The benefits of this type of work are difficult to quantify, since they accrue in terms of accidents and downtime that are avoided. Successful solutions can be deployed across the nation's natural gas infrastructure. To the extent that these solutions are developed by California companies, there will be additional benefits to the state in terms of economic development.

Ratepayer Benefit (Check one or more.)

☒ Promote greater reliability

☐ Lower costs

☒ Increased safety

☐ Societal benefits

☐ GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative:

75. Mitigating Hazards Associated with Natural Gas Pipeline Ruptures

Issues or Barriers
While significant research is underway to prevent pipeline explosions, very little research has been conducted to mitigate the hazards (including blast, fire, and projectile-induced damage) associated with explosions. Affordable and effective technologies are needed to mitigate the consequences of explosions in high impact areas.

Initiative Description and Purpose
California has an extensive natural gas pipeline network. While utilities, pipeline operators, and regulatory agencies are making every effort to ensure the safety of California's pipeline infrastructure, the San Bruno incident is evidence that accidents happen. It would be prudent to examine ways to mitigate the hazards that can result from a ruptured pipeline and implement them as needed in high-consequence areas.

Stakeholders
Ratepayers, pipeline operators, and utilities would benefit.

Background and the State-of-the-Art
Some funding for pipeline safety research is available through industry organizations, such as Pipeline Research Council International, and government organizations, such as the Department of Transportation's Pipeline and Hazardous Materials Safety Administration. In addition, a substantial body of research has been undertaken by organizations such as the Department of Defense to identify concepts and materials to mitigate the consequences of explosions.
Our Laboratory evaluates the response of structures to severe dynamic loading. A fundamental understanding of explosions can be used to construct a chain-of-events analysis to identify and evaluate mitigation strategies for pipeline rupture. In general, strategies that disrupt the chain of events as early as possible have the greatest impact. SRI has conducted chain-of-events analysis. Funding to identify, evaluate, and test strategies to mitigating the hazards potentially resulting from a pipeline rupture would have broad safety benefits.
One of the most significant studies in this arena is "A full-scale experimental study of fires following the rupture of natural gas transmission pipelines," by M.R. Acton, G. Hankinson, B.P. Ashworth, M. Sanai, and J.D. Colton, ASME International, *Proceedings of the International Pipeline Conference 2000*, Calgary, 1-5 October, 2000.

Justification
According to the Energy Information Administration, California is ranked the second largest natural gas consuming State. The impact of even one pipeline accident can be catastrophic. The rupture to PG&E's pipeline in San Bruno that occurred on

Sept. 9, 2010 killed eight people. Some reports put the total cost related to the blast (including money spent on repairs stemming from the blast) at over $1billion.

Ratepayer Benefit (Check one or more.)

☒ Promote greater reliability

☐ Lower costs

☒ Increased safety

☒ Societal benefits

☐ GHG emissions mitigation at the lowest possible cost

☐ Economic development

Name of Initiative:

76. Predicting the Remaining Useful Life in Gas Pipelines

Issues or Barriers
Our company has developed a technique, FRActure Surface Topography Analysis (FRASTA) to determine the growth history of a crack [1]. When linked to operating practices, this information can yield important insights into how and why structures such as pipelines fail. SRI has applied this technique to identify the cause of a wide variety of past failures, most recently the failure of a thruster on the Space Shuttle [2]. With additional investment, this could lead to a predictive capability.

Initiative Description and Purpose
This technology enables the determination of crack nucleation times and rates of crack growth in actual failed pipes. This information is necessary to develop and validate computational capabilities for assessing the remaining useful life.

Stakeholders
Owners, operators and others responsible for the safety of gas pipelines.

Background and the State-of-the-Art: FRASTA has been used successfully in multiple scenarios. For example, the crack history of a failed 22-year-old boiler tube in a hydroelectric plant was reconstructed from analysis of the failure surfaces [3]. The starts, stops, accelerations and decelerations were correlated with plant operation history. As a result of the analysis, the plant operator was able to set inspection intervals and plan for repair, rehabilitation, and component replacement.
In addition to building a library of information on crack nucleation times and rates of crack growth from actual pipes, FRASTA is ready to be upgraded for use on new, state-of-the art confocal microscopes.

Justification: The ability to predict with more certainty the remaining life of an aging pipeline will enable pipeline operators to make more informed repair/retrofit/replace decisions, thereby avoiding costly, disruptive, and possible fatal pipeline failures.

Ratepayer Benefit (Check one or more.)
- X Promote greater reliability
- Lower costs
- X Increased safety
- X Societal benefits
- GHG emissions mitigation at the lowest possible cost
- Economic development

[1] Fracture surface topography analysis (FRASTA)—Development, accomplishments, and future applications, by Takao Kobayashi and Donald A. Shockey, *Engineering Fracture Mechanics*, 2010, Elsevier Ltd.

[2] Replaying the fracture process of a failed space shuttle orbitor thruster, by Takao Kobayashi, Donald A. Shockey, and Jeremy B. Jacobs, *Journal of Failure Analysis and Prevention*,vol 12, No. 6 583-593, 2012, Springer.
[3] Deducing the Crack History in an Aged Boiler Tube from Fracture Surface Topography, by Takao Kobayashi, Donald A. Shockey, Gabriel Ogundele, David D. McNabb, an Duncan Sidey, *Journal of Testing and Evaluation*, July 1994

Name of Initiative

77. Improvement of Airborne Natural Gas Leak-Detection System

Issues or Barriers
Plumes from leaking natural gas lines disperse in the atmospheric boundary layer in a turbulent, chaotic manner. Surveillance flights searching for evidence of such plumes will be typically flown at a minimum safe altitude (usually 500 feet AGL), requiring that the airplane fly a substantial distance downwind of a pipeline to allow the plume time to rise to 500 feet while moving downwind. Once the airplane is in the proper position and detects a large methane enhancement, a stochastic back-trajectory is estimated to identify the most likely region of the source of the leak. Both the optimum downwind distance and the back-trajectory require accurate, yet probabilistic, estimates of the winds in the layer between the surface and 500 feet, altitudes that stretch the applicability of standard surface layer dispersion theory.

The second major issue is separating actual leaks from natural variability, i.e. above wet lands, ranches, and other non-fossil fuel sources of methane. Isotopic analysis will not likely provide any insight because the enhancements from a typical plume crossing are too small (e.g. 50 ppb on a background of 1800 ppb) and the isotopic ratio will not change substantially in those plumes. Some combination of plume shape and historical data will be necessary to identify actual leaks, or possibly the development of another gas species to fingerprint either the natural or fossil source of the methane.

Finally, a large body of observational data is necessary to statistically verify the methodology and improve our general understanding of low-level natural gas dispersion. With support from the Pipeline Research Council International (PRCI), we have performed roughly 40 flight hours to date as proof-of-concept for the proposed technology. Nevertheless, much more testing is needed in a variety of weather conditions, and over many types of terrain to expand the efficiency of the technology. Flight costs currently run $450 per hour and the proposed research would ideally include a minimum of one hundred hours of flight testing.

Initiative Description and Purpose
Detection of transmission line leaks is challenging. Walking the line is slow and expensive, and many areas are remote and inaccessible on foot. LIDAR technologies have shown promise but suffer from navigation issues resulting from the need to keep the LIDAR system directly over the pipeline. Additionally, helicopter operations are, by comparison, considerably more expensive (fixed-wing flights are typically 1/3 the cost.) With continued support from PRCI in tandem with the proposed grant, we could make large strides in developing a readily commercialized product of a fixed-wing aerial surveillance platform for wide-scale adoption by natural gas line operators worldwide.

Stakeholders
PG&E, CPUC, SDG&E, SoCalGas

Background and the State-of-the-Art
With primary funding from PG&E, the Pipeline Research Council (PRCI) commissioned our company to develop and test a detection system aboard fixed-wing aircraft. The system was tested in June over a series of unknown leaks provided by Enbridge near Mineral Wells, Texas. We were able to find all the leaks to various levels of accuracy, but also found several leaks that were not subsequently validated by ground crews. Testing has been performed on two different commercial greenhouse gas analyzers, manufactured by Picarro and Los Gatos Research. As was validated in Texas, significant progress has been made on the in-flight system for navigation and leak detection. In order to improve the predictability of the leak origination, however, the next leap of efficacy in the methodology will require extensive field testing supported by theoretical, numerical modeling.

Justification
Once this technology is accepted, the cost of operation will be much less than any present technology. Pipelines are routinely patrolled for intrusions with fixed-wing aircraft; these same aircraft could be fitted with the required equipment for approximately $50K each.
Once this equipment has been added, existing flights could then perform both the visual detection of intrusions, as well as the leak detection, with the specifics of flight path targets and identification of likely leak locations provided by open source software developed under this project.

Ratepayer Benefit (Check one or more.)
x Promote greater reliability
x Lower costs
x Increased safety
Societal benefits
x GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative:

78. Sealing Leaks in Natural Gas Lines with Aerosols

Issues or Barriers

Although a similar process has been successfully applied in the HVAC duct industry, the proposed idea to use aerosols to seal underground gas pipes faces three key barriers: 1) lack of data on the potential of this technology to seal leaks in gas pipes, 2) actual and perceived technical challenges that cause this technology to be viewed as high risk by individual utilities, and 3) the generally conservative and risk-averse nature of the natural gas industry. An effort similar to that proposed herein has been proposed by different companies to individual gas utilities; however their responses essentially reflected the above described barriers.

Initiative Description and Purpose

We propose to develop, laboratory test and demonstrate a remote sealing technique for low and medium pressure compressed-gas systems to prevent gas leaks in aging infrastructures (e.g., compressed-air and natural-gas distribution systems). Aerosolized sealants will be introduced into the systems and tailored for remote deposition at small leaks (e.g. joints, pitting holes). The objective is for deposits to occur only at leaks requiring sealing, as has already been achieved for HVAC systems with lower-strength materials, and more recently with a different material to seal leaks in building envelopes. The key to our success will be to produce and demonstrate sealant aerosols that cure in time frames that facilitate adhesion and cohesion at the leak sites, but allow the distribution system to be put back into service quickly. It may even be possible for the distribution system to remain in use during sealing. High strength biological adhesive materials will be explored, and may provide the added benefit of being non-toxic and non-fouling at the point of end-user combustion. In addition, the technology developed may also be used to mark leaks in high-pressure gas pipelines for future safety inspections.

The proposed effort attempts to address the identified barriers by a) providing missing performance data, b) addressing multiple technical challenges, particularly the issues of sealant strength, cure time, and system component protection, and c) partnering with

Stakeholders

The key stakeholders in this area are all of the natural gas utilities in the state of California, as well as other such utilities throughout the US. The proposed idea has been vetted at the highest levels of Sempra Utilities, and they are very supportive of the idea. In addition, our company has developed a partnership with GTI, which is the key research institution for the natural gas industry in the US. This partnership, in addition to providing unique facilities and expertise, should help provide nationwide credibility to the results of this effort.

Background and the State-of-the-Art

Past and current research related to this problem is focused on leaks in HVAC ducts and building envelopes, although a number of non-aerosol technologies have been proposed or are currently being used by the industry for gas leak sealing. Recent successes in materials and atomization systems for envelope sealing considerably improve the probability of success for the proposed process in higher pressure natural gas and compressed-air systems. The proposed applied research includes proof of concept for this particular application, as well as bench scale and prototype testing. A related research program to characterize leaks in natural gas pipelines in California is currently being conducted for the California Energy Commission by Marc Fischer at Lawrence Berkeley National Laboratory.

Justification
According to 1988 estimates, 1% of natural gas used within the US is lost to leaks in the transport system. Using that leak rate with today's US annual gas consumption of 23 x 1012 cubic feet, approximately $1.4 Billion worth of natural gas is escaping via leaks in the US alone. Thus, the value of this project to California ratepayers will be provided not only by the statewide reduction of natural-gas losses (and greenhouse gas emissions) that are ultimately paid for by ratepayers, but also by the increased safety of the natural gas infrastructure in the state, and the likely revenues from around the country, and potentially around the world, from licensing of the sealing technology developed.

Ratepayer Benefit (Check one or more.)
- x Promote greater reliability
- x Lower costs
- x Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

Name of Initiative:

79. Detection of Methane Leaks in the Infrastructure, Transport, and Production with a methane tunable diode laser.

Issues or Barriers

One of the most critical questions with respect to the natural gas infrastructure is the methane leak rate during production, transportation and from other aspects that are considered to be part of the handling process. With potential leak rates ranging anywhere from 2-6 percent, this issue has a tremendous impact on not only the economics of natural gas for the rate payer, but also threatens to potentially eliminate any environmental benefits that can be obtained through the use of natural gas. These benefits, such as a cleaner fuel source that mitigates greenhouse gas contributions, may not be as significant if the leak rates obviate this.

Initiative Description and Purpose

The goal of this program will be to implement and test a technique that can be broadly used for the measurement of leaks through the natural gas infrastructure and at transport and production sites. Our entity has developed and implemented at tunable diode laser for the measurement of methane. This instrument is currently being used in the large study being conducted in Texas. The goal of this initiative would be to test and implement this instrument in California. As part of the work done in Texas, tests included acetylene as a tracer to ensure contributions from the pipeline measured for CH_4 could easily be distinguished from those of background levels. The measurements were conducted both upwind and downwind so flux rates could be established.

Stakeholders

The stakeholders for this initiative would be wide ranging, and would include rate payers, natural gas producers and suppliers, and environmental regulators.

Background and the State-of-the-Art

Currently, there is a large scale study to evaluate methane leakage rates being conducted by the Environmental Defense Fund in conjunction with the University of Texas, other Universities, and leading natural gas producers. One of the primary instruments being used for the quantification of methane leaks in this study is a methane tunable diode laser (TDL). TDL's are highly specific lasers targeted at measuring methane emissions. This technique allows the measurement of extremely low levels of leaks over wide areas near production or supply sites. The tests were done concurrently with acetylene as a tracer as well as done simultaneously upwind and downwind over large area sources. The measurement

method is very sensitive and can easily range over small sources (leak tests) to large area sources (overall emission tests).

Justification
The primary benefit of this program would be extremely significant if infrastructure leaks can be identified and reduced. With leak rates between 2-6%, this could potential represent a potential savings on the order of 2-6% of the entire amount of natural gas utilized in the state.

Ratepayer Benefit (Check one or more.)

- ✓ Promote greater reliability
- ✓ Lower costs
- ✓ Increased safety
- ✓ Societal benefits
- ✓ GHG emissions mitigation
  Economic development

Natural Gas – Proposed Research Initiative

Program Area:

Energy Related Environmental and Climate Change.

Develop effective approaches to evaluating and resolving environmental effects of natural gas production, delivery and use; and explore how new natural gas applications and products can solve/mitigate environmental problems; complement research to inform policy associated with climate change, air quality and aquatic resources.

Name of Initiative

80. Integrated Absorption Process for Upgrading Renewable Natural Gas Air Quality and Climate Impacts of Natural Gas Production and Use in California

Issues or Barriers

California is fortunate to have two large potential sources of natural gas, the Monterey shale formation with an estimated 1.5-2.0 trillion cubic feet of gas and biomass that can form methane from agriculture and urban wastes (about 20 million bone dry tons/year). Production of gas from these sources has a number of barriers. Two important concerns are their impacts on air quality, health, and climate. California has legislation that encourages the use of natural gas and reduction of wastes: the Low Carbon Fuel Standard, the Climate Bill AB32, and the Integrated Waste Management Act. Only 15% of the potential biomass resource is being produced because of technical and policy issues (permitting difficulties and unclear incentives). Biogas and shale gas production are motivated by the need for environmentally benign domestic energy sources, and in the case of biogas production—to contribute to the solution of a waste removal problem. Gas production creates additional waste problems that can be partially ameliorated with technology. Production of methane from manure using digesters produces nitrogen and sulfur compounds that are emitted as NOx and SOx from combustion that are precursors to ozone and PM. In general, biomass electricity generation may have comparable uncontrolled NOX emissions but have less sulfur emissions relative to oil and gas generation sources. The emissions of NOx from biomass energy generation vary by feedstock with wood containing less nitrogen then perennial herbaceous crops or crop residues [Cook and Beyea, 2000]. Current requirements for expensive air pollutant emission controls have prevented the expanded use of biomass feedstock for electricity generation in California [CEC, 2011]. Hydraulic fracturing or fracking involves using fluid mixtures to fracture the shale deposits. Fracking has raised public concern regarding the safety and potential health effects of domestic shale gas production. Recent studies [Alvarez et al., 2012] of fuel switching in different combustion systems have demonstrated that switching to natural gas as fuel can actually increase radiative forcing for significant time periods whose durations depend on the amount of methane fugitive emissions emitted during production, delivery, and utilization.

Initiative Description and Purpose

The proposed study objective is to determine the air quality and climate impacts of natural gas produced from urban and agricultural biomass and from shale deposits in California. We will conduct a modeling study of air quality in Central California using a meteorology modeled coupled to a chemical transport model for a modeling period of one to two months in the late summer and in the wintertime. This region was selected because of its air quality and because it is likely to be the location of considerable potential biogas and shale gas production. Pollutants to be modeled include ozone, PM in its various size cuts and chemical classes, and air toxics. We will use the Weather

Forecasting Model (WRF) and EPA's Community Multiscale Air Quality Model (CMAQ) at high resolution (4km x 4km). Considerable effort will be placed on estimating emissions and sources of these will be production, fuel transport, and fuel use. The cited references indicate that the carbon footprint is dominated by fuel use; hence, it must be included to provide an accurate carbon footprint. Our group has considerable experience in developing emissions inventories, especially those associated with diesels and electricity generation in California. We will start with EPA's National Inventory for California that contain data for the counties of interest in California provided by the California air Resources Board. We will consider the rate of natural gas emitted during unconventional gas extraction processes such as well completion and workovers; and the lifetime production of wells, which determines the denominator over which lifetime emissions are placed. We will develop scenarios for the growth of production from each of these sources, and investigate their impacts on air quality and climate using a host of modeling tools like standard statistical ozone forming potential, sensitivity studies, changes in limiting reagents in production regions for both ozone and PM. Seasonality will also be considered in this effort. The approach of Alvarez et al., the Technology Warming Potential, will be used to determine the carbon footprint for the fuels in different combustion systems. The final year of the research will focus on quantifying changes in air quality and climate that will result form improvements (emissions reductions) in key steps of production identified by the sensitivity studies. We envision that there would be a complementary experimental program to provide emission data.

Stakeholders

The rate payers, the natural gas production industry, utilities, environmental groups, policy makers, would greatly appreciate that sound science had been applied to investigate the impacts of natural gas production on air quality, health, and climate.

Background and the State-of-the-Art

Recent expansion in US shale gas production has greatly reduced natural gas costs, but has also created problems. Kargo et al. [2010] describe the environmental issues associated with Marcellus shale gas production: fracking fluid and deposit formation chemicals are found to include a variety of non-toxic and toxic chemicals, some of which are carcinogens. Fluid composition is highly proprietary, and each company has its own version. This is very challenging to public officials and the scientific community, who want to conduct appropriate research to inform policy so that public health and safety are assured. Air emissions associated with shale gas are volatile hydrocarbons from fracking and production and include diesel emissions (NOx, hydrocarbons, and organic and black carbon particulates) from power generation on site. The emissions tend to give rise to high ozone and air toxic concentrations and high particle mass (PM) loadings. There are six or more life cycle analyses of the carbon footprint of shale gas, and a meta analysis of these by Weber and Clavin [2012] followed by a recent study of natural gas by Alvarez et al. [2012]. The studies demonstrate that the methane emission reductions are essential for minimizing the natural gas carbon footprint and that emission uncertainties must be reduced. Alvarez et al. introduce the concept of

technology warming potential as an approach for comparing the radiative forcing from combustion systems fueled with natural gas versus those fueled with oil or gas over a time period extending out to 200 years or longer, considering production and transport emissions. They also examined fugitive methane emissions reductions as a function of time to determine when climate benefits are achieved. Their approach will be used here. Other important concerns are that large methane emissions will change global ozone background levels, affect the oxidizing nature of the atmospheric, and are likely to affect secondary PM production. In summary, there is great potential for domestic natural gas from biomass and conventional and unconventional resources, great uncertainty in emissions associated with its production, large uncertainties associated with its carbon footprint, and great fear on the part of the public associated with concern for its impacts on air quality and health.

Justification

This research would contribute to improved ratepayer acceptance of these technologies and reduce their concerns regarding safety and health. Results should guide public policy toward achieving a higher level of safety and should suggest how pollution attributable to these sources might be abated to safeguard public health. This should open the pathway for larger scale economic development. Rate payer benefits: increased safety, societal benefits, suggestions for GHG mitigation, and economic development.

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Name of Initiative

81. Development of nanocomposite polymer membranes to reduce methane emissions in California

Issues or Barriers

Emissions of methane (CH4) from fossil fuel extraction, processing and distribution, agriculture and waste management comprise about 20% of greenhouse gas (GHG) emissions globally (Weubbles and Hayhoe, 2000). Within California, CH4 emissions totaled 32 million metric tons CO2 equivalent (MtCO2e) in 2009, corresponding to 7% of the total GHG emissions (CARB, 2011). While emissions of the other two major GHGs (CO2 and N2O) have been decreasing in California, CH4 emissions increased by more than 14% between 2000 and 2009. Many of these emissions are not captured because it is uneconomical to do so, or they are sufficiently dilute that burning is ineffective. The mitigation technology we propose is at an early R&D stage and not yet ready for commercialization.

Initiative Description and Purpose

A chemically selective, nanocomposite polymer membrane material capable of efficiently separating CH4 from diluent gases such as N2 or CO2 would be an ideal way to curb CH4 emissions, because it could work passively and in theory be inexpensive to produce. The main emissions sources targeted in CA would be from landfills and manure management, though if the technology proves sufficiently inexpensive, it may displace existing capture methods in other sectors (e.g., fossil fuel extraction, processing and distribution) as well. While prototype separations of CH4 and CO2 have been demonstrated at the bench scale (see Background below), a commercial technology is not yet available, as nanocomposite polymers are an emerging field. Funding is required to develop and identify promising membrane materials suitable for commercialization, and perform detailed cost and implementation assessments.

Stakeholders

Natural gas extraction industry, utility gas operators, environmental groups, CA energy policymakers, and utility ratepayers would all be supportive in principle, as the technology reduces GHG emissions while saving money and resources.

Background and the State-of-the-Art

CH4 emissions from fossil fuel processing (i.e., refineries) are minimal in CA, while “fugitive” CH4 emissions from fossil fuel extraction and distribution are rarely, if ever, captured, because of minimal leakage per site, large number of leaks, and high cost of capture. Major remaining CA sources of CH4 are from landfills and manure management, and can be more easily captured because the source can be concentrated in a small area. CH4 produced at these locations is often captured, but the purification process can be hazardous and expensive. Two common methods of purifying are activated carbon and amine scrubbing (Abatzoglou et al., 2009; Spokas et al., 2006). In both cases, the absorbent material must be regenerated, resulting in

hazardous by-products, material degradation, and high energy costs. Uncaptured CH4 remains a significant source of statewide CH4 emissions (CARB, 2011). Novel nanocomposite membranes can efficiently address these concerns. The passive nature of the materials inherently reduces energy consumption, and the absence of an intermediate product minimizes any formation of hazardous waste. Earth-abundant materials and large-scale manufacturing should allow for inexpensive production. Hybrid organic-inorganic nanocomposite membranes present the opportunity to incorporate high flux capabilities of polymer membranes and high selectivity capabilities of inorganic nanomaterials. Specifically, the polymer acts as the support for the inorganic material, whose primary function is to provide chemical selectivity of a particular gas (e.g., CO2, CH4, etc.). Previous studies on nanocomposite membranes used nanomaterials as "fillers," generating increases in free volume and 2 permeability, with detrimental effects on selectivity (Matteucci et al., 2008). Alternatively, two studies have shown that the use of silver-treated MgO (Hosseini et al., 2007) and TiO2 (Rubal et al., 2008) nanoparticles have chemical interactions with CO2, increasing both selectivity and permeability over CH4. A recent study showed absorption of CO2 on MgO nanoparticles of approximately 5 nm in diameter (Ruminski et al., 2011). These studies show promise for CH4 purification from gas streams.

Justification

The state GHG inventory reports 17 MtCO2e of CH4 from landfills and manure management in 2009, or approximately 53% of total CH4 emissions (CARB, 2011). We estimate that nanocomposite polymer membranes have the technical potential to capture all of this CH4, resulting in energy, GHG and ratepayer cost savings. Almost no data exists on the fraction of CH4 emissions already captured from landfills and manure management, though the U.S. Environmental Protection Agency estimates capture efficiency from managed landfills at 75% (Sullivan, 2010). If the technology is sufficiently inexpensive, it may also replace existing capture techniques in these and other sectors.

Ratepayer Benefit

- ☐ Promote greater reliability
- x Lower costs
- x Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

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Name of Initiative

82. Reducing methane and VOC emissions from hydraulic fracturing, natural gas storage and transport in California.

Issues or Barriers
Hydraulic fracturing (fracking) is revolutionizing natural gas production in North America. According to a recent report, the US may become a net energy exporter by 2025. Substitution of coal-based by natural gas power plants is curbing the US GHG emissions as a short- to mid-term bridge to a future carbon-neutral energy matrix. Key barriers to the safe implementation of fracking are the environmental impacts on groundwater, surface water and air pollution, as well as releases of methane, a strong GHG. Significant efforts are currently dedicated to identify remediation technologies that can mitigate these impacts and meet strict regulatory levels in a cost-effective way. While most efforts have been aimed at the treatment of “flowback” water, less emphasis has been placed in air treatment. The US EPA issued the first air quality regulation for fracking in April 2012 (1), and California may follow suit soon (2).

Initiative Description and Purpose: Natural gas provides almost one-third of the state's total energy requirements and will continue to be a major fuel in California's supply portfolio. Natural gas systems are the largest anthropogenic source of methane emissions in the US with 215 Tg CO2 equivalents of CH4 emitted into the atmosphere (3). During the life cycle of an average shale gas well 3.6 to 7.9% of its total production is released as methane (4). These emissions can be mitigated through technologies that eliminate or reduce methane levels and associated hazardous air pollutants (HAPs) impacting air quality, public health and climate. We propose to mitigate methane and volatile organic compound (VOC) emissions from the natural gas production, storage and transportation infrastructure using a combination of modular photocatalytic air treatment units and a wireless network of smart methane monitors that allow for detecting levels that exceed regulations combined with automatic activation of the air treatment devices. Our approach will be to design and test the proposed technology as a proof of concept, followed by a demonstration of a pilot-scale prototype in the field. We will evaluate the effectiveness of photocatalytic air cleaning technology to reduce the emissions of GHGs (methane, N2O) and HAPs (e.g., benzene, toluene, hexane, xylenes, ethylene glycol, methanol, ethyl benzene and 2,2,4 trimethylpentane) that occur during venting and flaring in natural gas extraction with hydraulic fracturing (5). We will also consider other sources such as impounded flowback water at the well site and methane leaks during storage and transport. In addition, we will model the potential impacts of this mitigation technology on the local and regional air quality to assess its effectiveness with respect to current conventional technologies.

Continuous methane monitoring with wireless communication will be incorporated into the design and operation of the air treatment technology and related leak detection, as well as in storage and distribution systems. Two-way communication via wireless sensor networks (WSN) will allow efficient process control and simultaneous monitoring

of methane concentrations at different locations over all stages of natural gas production and distribution. The technology will adapt WSN designs that already exist for combustible gases, consisting of sensor nodes with currently available small methane sensors (based on catalytic, semiconductor and/or optical principles), microcontrollers, wireless actuators, relay nodes (radio chips), and data processing and visualization (6-7).

Stakeholders

We will seek support for the initiative from three different groups of stakeholders:

1) our network of industrial partners in the field of environmental remediation, including large corporations such as Saint Gobain and start-ups developing novel air and water treatment technologies,
2) other researchers
3) at least one gas field operator (e.g., Chevron Corp.) to obtain access for sampling and pilot testing and/or utilities (e.g. SoCal Gas) interested in controlling methane emissions along the storage and transport infrastructure.

Background and the State-of-the-Art

In 2009, the total US emissions of methane from natural gas-related hydraulic fracturing amounted to 11,243 million m^3 of methane (8). The majority of these releases occurred during well venting and flaring (> 50%), from natural gaspowered pneumatic devices (1,897 million m^3), storage tank venting (397 million m^3) and the use of glycol dehydrators and pumps (538 million m^3). While “green completion” appears to be the best approach for recovering emissions during well completion and initial gas production (5), photocatalytic oxidation may be an appropriate approach for handling lower flow rates of methane and VOC emissions at other points of the production process, especially from dehydrators, pneumatic devices and storage tanks, which together account for 25% of the total fugitive methane emission. Over the past two decades, photocatalytic oxidation using titanium dioxide and UV irradiation has proved to be an effective technology for the oxidative conversion of airborne pollutants –including methane– to CO2, minerals, water vapor and partially oxidized byproducts (9). Our team has demonstrated experience in the development of photocatalytic systems and in the evaluation of their performance for air treatment under realistic conditions (10-12). We have also recently described how wireless sensor networks for air pollutants can improve atmospheric monitoring using as an example a new LBNL/UCB sensor for airborne particles that can communicate via WSN through a cell phone (13).

Justification

Minimizing methane and VOC emissions during fracking operations, storage and transport will provide several benefits to natural gas ratepayers, by reducing the GHG footprint of natural gas roduction and distribution (currently responsible for 40% of total US emissions), and eliminating or reducing impacts on air quality associated with the release of air toxics (e.g.,benzene) and ozone precursors. Our results will assist industry to improve monitoring and control techniques and ensure adherence to future

State regulation for GHG and HAP emissions. If successful, our approach will also enable creation of new “green” jobs in the oil and gas industry. In shale gas production, total methane emission per well ranges was estimated between 50,000 and 90,000 m^3 (14). In 2009, California had 1639 wells for natural gas production (15) with estimated 600 new wells fracking every year. Based on these estimates, total fugitive methane emissions in California may be between 82 and 147 million m^3. The proposed technology can eliminate up to 25% of this emission related with dehydrators, tanks and pneumatic pumps, equivalent to 20 – 37 million m^3 and a value of approximately $3–$5 billion assuming an average market gas price of $5 per thousand cubic feet (16). The cost of the proposed technology would be low compared with the scale of the operation: a prototype system would cost between $5K and $20K in capital investment and incur low O&M costs. We estimate the market to be very large considering the large number of tanks, dehydrators and pumps that can be equipped with these treatment devices, which could significantly reduce thecapital and operational investments through economies of scale.

Ratepayer Benefit

- ☐ Promote greater reliability
- ☐ Lower costs
- x Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- x Economic development

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Name of Initiative

83. Hydraulic Fracturing for Natural Gas and the Impact on Overlying Freshwater Resources

Issues or Barriers
There has been rising concern and opposition expressed by environmental groups and the public over the safety and impacts of hydraulic fracturing practices for the development of natural gas throughout California, and its possible contamination of overlying freshwater resources. In the past, the Department of Conservation's Division of Oil and Gas and Geothermal Resources (Division), the agency responsible for regulating oil field operations, has protected sources of freshwater through well construction standards. However, the Division has not regulated hydraulic fracturing or required the submission of any records in regards to hydraulic fracturing operations. As a result, there is a lack of empirical data concerning the possible evidence of damage that hydraulic fracturing has on overlying protected water resources.

Initiative Description and Purpose
To research the impact of hydraulic fracturing on overlying freshwater resources in order to distinguish if any contamination or damage is evident. As the Division enters into a formal rulemaking for hydraulic fracturing in early 2013, this information would immensely aid the Division in factors to be aware of when reviewing past and future projects in order to adequately regulate hydraulic fracturing in California and protect all the natural resources.

Stakeholders
Environmental groups and the oil and gas industry.

Background and the State-of-the-Art
Hydraulic fracturing, also known as "fracking", is the high-pressure injection of a mix of fluids, chemicals, and substances called "proppants" into an oil or gas reservoir in order to fracture the formation, allowing oil or natural gas to flow back to the well. Fracturing the rock is necessary to extract natural gas from formations in which the pore space in the rock making up the natural gas reservoir is too tight to allow the flow of fluids or gasses to the well. Without a man-made fracture, the gas cannot be recovered.

In California, hydraulic fracturing has become a regular and highly successful practice as a production stimulation method for more than 30 years. It is estimated that currently in California about 650 wells are hydraulically fractured a year, and of those wells approximately 20 are solely for the production of natural gas.

Currently, the United States Environmental Protection Agency (EPA) is involved in extensive research for their "Study of the Potential Impacts of Hydraulic Fracturing on Drinking Water Resources." The final draft report is expected to be released in 2014,

however, it does not look into the impacts of hydraulic fracturing specifically in California.

Justification
Development of natural gas responsibly in California offers a clean form of energy, helps ensure energy security, and promises significant environmental and economic benefits for the future.

Ratepayer Benefit

- ☐ Promote greater reliability
- ☐ Lower costs
- x Increased safety
- x Societal benefits
- ☐ GHG emissions mitigation at the lowest possible cost
- ☐ Economic development

Name of Initiative

84. Methane Emission Mitigation Supply Curves: Leakage in Commercial and Residential Buildings

Issues or Barriers
Atmospheric measurements of methane emissions from urban areas are much larger than bottom-up inventories from gas distribution (e.g., Wennberg et al., 2012). Leakage from buildings has been proposed to explain this discrepancy, yet little is known about the extent of leakage of natural gas in buildings and the cost effectiveness of control strategies. Lack of such information impedes California's ability to meet the goals of AB32 in as cost efficient a manner as possible.

Initiative Description and Purpose
The purpose of this initiative is to

1. identify sources of natural gas leakage after the distribution company meter in a sample of different commercial and residential building types
2. estimate emission rates from each source of natural gas leakage
3. assess leak reduction strategies, cost and technical and market potential
4. develop methane emission mitigation supply curves for selected types of commercial and residential buildings in California

Stakeholders
NG utilities and industry organizations such as Gas Technology Institute and American Gas Association; environmental organizations (e.g., Environmental Defense Fund (EDF)) and regulatory bodies (federal, state, regional and local); California ratepayers.

Background and the State-of-the-Art
EDF, USEPA and others are working to measure methane releases from natural gas production, transmission, and delivery operations. To date, limited work has focused downstream of natural gas meters serving homes and businesses.

Justification
California homes and commercial businesses typically consume 35% of the state's 2.3 trillion cubic feet of NG per year. Wennberg et al. (2012) suggest that 2.5-6% of gas delivered to LA basin customers is leaked. Leakage reduction could save Southern California Gas ratepayers $3 million/year or more – and scalable amounts for other California gas ratepayers – and reduce up to 17 million metric tonnes carbon dioxide equivalent GHG emissions per year, as well as improve consumer and business safety.

Ratepayer Benefit

☐ Promote greater reliability

x Lower costs

- x Increased safety
- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- ☐ Economic development

Name of Initiative

85. Methane Emission Reduction Supply Curves: Medium-Duty and Light-Duty Vehicles

Issues or Barriers
Natural gas (NG) is being pursued by the California Energy Commission (CEC) and others as a greenhouse gas (GHG) emission reduction strategy for the transportation sector. However, Alvarez et al. (2012) found that NG leakage on vehicles negated GHG reduction benefits over most time horizons. This assessment relied on only one estimate of vehicle leakage from an older paper that the author's admonished should be improved and updated. Little effort has been spent to determine NG leakage and assess mitigation options and costs of those options, impeding California's ability to meet the goals of AB32 in as cost efficient a manner as possible.

Initiative Description and Purpose
The purpose of this initiative is to

1. identify sources of natural gas leakage during fueling, on-board storage and use from a different types of natural gas-fueled light and heavy duty vehicles
2. estimate emission rates from each source of leakage
3. assess leak reduction strategies, costs, and technical and market potential
4. develop methane emission mitigation supply curves

Stakeholders
Natural gas producers, engine and vehicle manufacturers; environmental organizations (e.g., Environmental Defense Fund (EDF)) and regulatory bodies (federal, state, regional and local); California ratepayers.

Background and the State-of-the-Art
EDF, USEPA and others are researching methane emissions from natural gas production, transmission, and delivery operations as well as from heavy-duty vehicles. To date, limited effort has focused on emissions from light and medium duty vehicles.

Justification
In its Integrated Energy Policy Report, the CEC estimates by 2030 250 million gallons of gasoline equivalent will be used for NG-fueled transportation. At the leakage rate cited by Alvarez et al. (2012), up 67,000 metric tonnes carbon dioxide equivalent could be avoided by reducing leakage, with savings of up to $1.5 million for California ratepayers.

Ratepayer Benefit

☐ Promote greater reliability
x Lower costs
x Increased safety

- x Societal benefits
- x GHG emissions mitigation at the lowest possible cost
- ☐ Economic development

Name of Initiative

86. Energy, Water and California Climate Modeling (EWCC)

Issues or Barriers

A core challenge for energy-economic-environmental modeling efforts is the ability to easily represent these integrated systems to broad, non-technical audiences for public education and decision making. The often segmented nature of data and system's thinking that addresses electricity (energy), environmental effects, aquatic resources (e.g., cooling water for power plants) and potential climate change issues make it difficult to tell the complete 'story' of a region or state, such as California. Such a tool presents a substantial effort of time and resources to develop. With this challenge comes an opportunity to link both the regional-scale modeling (e.g., water basins) to state-wide climate change initiatives such as using increasing amounts of natural gas to meet load requirements in cases where more renewables would otherwise be limited from entering the electricity market.

Initiative Description and Purpose

A user-friendly, transparent system dynamics based modeling effort has been underway at Sandia National Laboratories (SNL) for several years to model the energy-water nexus in the contiguous United States. This effort synthesizes the potential transition of the electricity sector from coal-based power to less CO2-intensive and water-intensive options such as natural gas and renewables. Using the Energy Power and Water simulation (EPWsim)1 model, the analysis will include higher-fidelity water basin information and energy transition options towards more natural gas for electricity in California. The purpose of this will be to run scenario options to model (1) the effects of increasing the natural gas share in the electricity sector, (2) calculate both the scale and location of water requirements and supplies (including non-potable) for power plant cooling within the state's borders, and within the overall gridsystem's boundaries (e.g., electricity produced out of state but used in California), and (3) the CO2 and other air pollution considerations resulting from a dramatic and/or gradual shift to natural gas based electricity production in the Western United States. The key to this modeling initiative is the webpage like interface for the underlying systems model that makes the analysis fully accessible to educational opportunities (e.g., highlighting the key energy, water and climate challenges of changing energy mixes) unlike many 'optimization' or large models that are often inaccessible to public and private parties.

Stakeholders

The key stakeholders include the California Energy Commission, its ability to promote learning with the public, private and regional governmental bodies about the interactive effects of the Energy, Water and California Climate-related engineered and social systems.

Background and the State-of-the-Art
Several modeling efforts at SNL dovetail directly into this research ideas call. First, the EPWsim model provides the basis for an energy-water decision support system that already allows planners in the Western and Texas Interconnection to analyze the potential implications of water stress for transmission and resource planning.2 This effort works through a strongly collaborative process between the Western Electricity Coordinating Council, Electric Reliability Council of Texas, Western Governors' Association, and the Western States Water Council. Next, the Water, Energy and Carbon Sequestration Model (WECSsim) is another decision support tool developed to calculate the potential performance, location and cost characteristics with a national CO2 storage program utilizing geologic saline formations.3 Finally, SNL is the only federal user of the Gas Pipeline Competition Model (GPCM) that provides a complete data description of natural gas pipelines, demands, supply, and storage for the United States. The overall EWCC research effort proposed here can develop scenario analyses of California's natural gas system and how changes to it affect the state and regional water use and CO2 management goals by synthesizing components from these three models. Additionally, a county specific level analysis could be developed where appropriate to calculate the number of jobs created and investment required for a natural gas transition by and for the customers in California.

Justification
The household ratepayers and manufacturing sectors will benefit the most from understanding future fuel options for the electricity sector to help plan their current investments today for more energy efficient (e.g., smart metering to reduce future demand) and/or renewable energy systems (e.g., a cleaner supply of electricity). Under potential Cap-and-Trade legislation, all forms of fossil-fuel based electricity may incur higher electricity costs passed on to the consumers. The EWCC tool will identify the lowest cost natural gas-supported options to meet these goals. Additionally, environmentally focused parties will be able to protect aquatic resources today that may be considered as potential cooling water sources for additional natural gas electricity generators tomorrow. Thus, at a minimum, this decision support tool will offer individual consumers the insights required to make more informed investment decisions, whereas at the maximum level, electricity planning boards will be able to forecast the water and economic impacts of more natural gas in California's electricity portfolio.

Ratepayer Benefit
☐ Promote greater reliability

☐ Lower costs

☐ Increased safety

X Societal benefits

X GHG emissions mitigation at the lowest possible cost

X Economic development

Natural Gas – Proposed Research Initiative

Program Area:

Natural Gas Related Transportation.

Accelerate the commercial viability of natural gas vehicles, improve energy efficiency of natural gas vehicles and advance the clean and cost effective production of renewable natural gas for transportation use.

Name of Initiative

87. Utilizing Natural Gas in Commuter Rail Applications

Issues or Barriers
Full adoption of natural gas in rail applications is limited by the high costs of retrofitting existing diesel locomotives. Other issues that need to be resolved include fully integration of large-scale natural gas engines to rail applications and on-board fuel storage.

Initiative Description and Purpose
We'd be interested in working with our technology partners, specifically natural gas engine developer Caterpillar, Inc. to demonstrate different natural gas engine/storage configurations on a passenger train in Northern California that operates between Stockton and San Jose. We would also examine the full greenhouse gas reduction benefits associated with this technology application. We would also investigate whether liquefied or compressed natural gas is the best fit for this application.

Stakeholders
CALSTART, Caterpillar, Inc., Westport Innovations, Altamont Commuter Express

Background and the State-of-the-Art
Some early demonstrations have been done outside the U.S. Natural gas was demonstrated in freight rail applications more than 15 years ago but no major initiatives resulted. The different injection technology configurations that need to be fully tested are dual-fuel (gas is ignited by the compression of the diesel) spark ignited, and high-pressure direct injection. A demonstration of the different technologies in this application would advance the state of the industry and better identify which technology configurations best suit commuter rail applications.

Justification
While rail locomotives are generally more fuel efficient than large on-road diesel engines, they remain large consumers of diesel fuel. The sector as a whole also consumes much energy. In 2010, consumer rail in the U.S. consumed 31.5 trillion BTUs of energy, a mix of diesel and electricity. In addition to the Altamont Commuter Express, potential California applications include the Capitol Corridor, Metrolink, and the San Diego-Los Angeles Express. Natural gas offers the potential of reducing total diesel use by 70% or more.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative

88. Optimal Modern NG Combustion System

Issues or Barriers

Implementation of modern combustion controls and energy generation with NG can address the following issues and barriers to clean NG energy and use in vehicles:

1. RANGE – Due to the low natural gas (NG) energy density large storage volume and high pressure is required to cover relatively short distances in comparison to other fuels such as diesel.

2. CONVENTIONAL DESIGN LIMITATIONS – **Camshafts/Spark plugs/2nd ignition fuel** - Current CNG engines generally include core engine control s that utilize mechanical controls, such as camshafts, which are based on designs that are over 100 years old. These engines have almost no control of the combustion process. Consequently, they require either spark plugs or a secondary fuel for ignition. Spark plugs greatly reduce the potential engine efficiency and range, and present ongoing maintenance issues. The need for a second fuel for ignition, such as diesel, requires costly additional equipment, including emissions aftertreatment devices, as well as extra size, weight, maintenance.

3. COMPETETIVE FUELS & TECHNOLOGIES– NG competes with many other fuels, now and in the future. Limited power, range, and cargo space, extra cost for implementation or conversion, and distance between fueling infrastructure can be influencing factors.

4. FOSSIL FUEL – A fossil fuel which contains carbon and consequently produces CO2, is believed to be endangering the survivability of life on the planet. Although NG contains less CO2 than fuels such as diesel, the CO2 generation of NG may become a barrier to long term use of NG.

Initiative Description and Purpose

By modernizing combustion controls and providing a system that can optimize NG use and even enable carbon free fuel made from NG, all the above outlined issues can be addressed in a practical manner. This companies Air Controlled Engine 'ACE' combustion management system replaces the mechanical camshaft engine controls. The system incorporates ultra-precise, fast, and intelligent digital hydraulic controls and electronics. The ACE approach enables the internal combustion engine to adapt and selfoptimize to large variations in fuels, fuel quality and varying operating conditions. This optimization occurs real time between, and during, operating cycles. Such controls can provide low cost, durable, high power performance with increased range, smaller packaging, lighter weight implementation, and cleaner, more efficient operation, without the disadvantages of conventional natural vehicles. ***The potential efficiency gain is estimated to be up to 50% improvement over existing spark ignition CNG systems.***

Stakeholders

Key stakeholders, in addition to this company, includes major fleets and natural gas fuel suppliers. This company Fleet Advisory Board includes a collection of major fleets including Wal-Mart, UPS, and eight others. Fuel suppliers interested in this company advanced engine control strategies include Southern California Gas Company, Clean Energy, Cheapeake, and a number of others. This compnay is also closely aligned with Calstart, the Clinton Foundation, and engine research at UCLA.

Background and the State-of-the-Art

This company has successfully completed a major first phase demonstration for California of the viability of modern engine controls in a CEC PIER Program. This company used a Cummins 15 liter ISX diesel engine that was converted to CNG supply, and retro-fit with Sturman camless air controls. The engine was supplied by Westport. The goal of the project was to demonstrate better than diesel efficiency and NOx levels lower than 0.2 gm/hphr. The engine was equipped with spark ignition, and was able to meet all of the Program goals. Presently, this compnay has completed an internal program using compression ignition (CI) in place of spark ignition for CNG on a Navistar I6 engine. The strategy was to accomplish HCCI (Homogeneous Combustion Compression Ignition) with the use of CNG only, without the need for a second fuel or spark ignition. The single cylinder test results have proven the feasibility of using ACE to accomplish CI and stable HCCI, called the 'holy grail' by industry engineers. Based on the positive results of the single cylinder tests, the original CEC ISX engine retrofit by this company is currently being converted from spark ignition to compression ignition for all six cylinders, and is being installed into this company's engine dynamometer for full engine test and demonstration for this company's Fleet Advisory Board and interested CNG suppliers.

Justification

Continuation and expansion of this companies testing and optimization made possible with additional appropriate funding can supply significant benefit to users and California, as well as the nation, with even global significance. Being a leapfrog technology in a depressed market, this funding and support can help bring this industry enabling technology to near certification level and propel it to commercial use. The President of NGV America has said that this companies technology answers all the remaining issues facing large scale natural gas use – increased efficiency, smaller tanks, and more distance and power, with a practical approach that reduces implementation and maintenance costs. In addition to the substantial financial benefit, practical replacement of gasoline, diesel and coal with cleaner and more efficient natural gas engines that can be used for mobility and stationary power, the environmental benefits can be enormous. National security, jobs and local and general economic benefit can increase significantly with the projected

Ratepayer Benefit – ALL CATEGORIES LISTED BELOW CAN BENEFIT

X Greater reliability X Increased safety X Societal benefits X Economic development
X Lower costs X Increased safety X Lowest Cost GHG emissions mitigation

Name of Initiative:

89. Modular, Reliable and Economical CNG Pumps for Fueling Small Fleets

Issues or Barriers

Compressed natural gas refueling stations are capital intensive. They require expensive equipment, permitting, utility hookups and site preparation. Gas compressors are expensive,
and require frequent maintenance and cause oil contamination of the fuel. Oil-free compressors are challenging, and expensive to operate and maintain. The high cost and complexity of compressors continue to represent a major barrier preventing quick build-out of natural gas refueling infrastructure.

Initiative Description and Purpose

Proposed is a modular, economical and reliable advanced oil-free intensifier/pump solution for
refueling small natural gas vehicle fleets. The proposed system is free of complex hydraulics
and seal systems of the existing compressors that require constant maintenance and are prone
to frequent breakdowns. The new natural gas pump system is designed to be contamination resistant, and allows greater expansion of fueling infrastructure, especially to service small
fleets.

Stakeholders

Stakeholders for this initiative are fleet operators and natural gas fuel providers.

Background and the State-of-the-Art

Currently used mechanical compressors are inefficient, and represent a high portion of the retail natural gas costs due to high capital costs and high operation and maintenance costs. New research in the area of gas compression (funded by the DOE) is focused on home refueling,
and not applicable for small fleet applications that require compression and dispensation of up
to 500 diesel gallon equivalent per day.

Justification

The proposed technology will provide natural gas ratepayer benefits as follows:

• Addresses one of the significant gaps in the industry, as identified by CEC (PIER Report
CEC-500-2008-044-F), that negatively affects progressive adoption of natural gas vehicles with the potential to consume 885 million gasoline gallon equivalent of natural gas in a decade

• Allows greater expansion of natural gas refueling locations, higher usability and quicker
adoption of natural gas as the fuel of choice for distributed small fleets

Ratepayer Benefits:

Promote greater reliability
Lower costs

Societal benefits
GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative:

90. Economical, Alternative Composite Tanks for On-Board CNG Fuel Storage

Issues or Barriers
The high cost of natural gas on-board fuel storage systems continues to represent a major barrier preventing quick adoption of natural gas vehicles, due to their high cost of acquisition.
Carbon fiber reinforced composite tanks offer significant reduction in weight, however at a high cost. Additionally, the global carbon fiber manufacturing capacity of 100,000 metric tons is insufficient to support any meaningful penetration of natural gas vehicles. Advanced material alternatives are urgently required to address this critical gap.

Initiative Description and Purpose
Proposed is a high-capacity lightweight compressed natural gas on-board fuel storage tank that is constructed from materials other than the current high-strength, low-modulus 'small tow' carbon fibers, which are very expensive and manufactured in limited quantities. The new tank is targeted for a price point that is well-below the current price points of lightweight Type III and Type IV carbon fiber composite compressed natural gas tanks.

Stakeholders
Stakeholders for this initiative are fleet operators and natural gas vehicle OEMs and aftermarket conversion businesses.

Background and the State-of-the-Art
Lightweight fuel tanks contribute to improved fuel economy, higher payload/passenger capacity, reduced emissions and reduced vehicle wear and tear. Carbon composite on-board fuel tanks are increasing in popularity due to their extreme lightweight compared to steel tanks, however costs 2-3 times the cost of steel tanks. Carbon fiber is also in short supply since the manufacturing process is capital and technology intensive. Alternative methods of constructing lightweight tanks are urgently required to ensure the continued growth of the natural gas vehicle industry.

Justification
The proposed technology will provide natural gas ratepayer benefits as follows:

- Addresses one of the significant gaps in the industry, as identified by CEC (PIER Report CEC-500-2008-044-F), that negatively affects progressive adoption of natural gas vehicles with the potential to consume 885 million gasoline gallon equivalent of natural gas in a decade
- Allows greater expansion of natural gas vehicles and quicker adoption of natural gas as the fuel of choice for California's commercial fleets.

Ratepayer Benefits:
Promote greater reliability

Lower costs
Societal benefits
GHG emissions mitigation at the lowest possible cost
Economic development

Name of Initiative

91. Near Zero Emissions Natural Gas Locomotive Engine Conversion

Issues or Barriers

Natural gas locomotive programs suffer from 'The Chicken or the Egg' syndrome. There is no private capital to do the technology development because there are no apparent customers. Freight and passenger railroads are not demonstrating much interest because they have effective monopolies making them fuel price insensitive which has allowed them to easily dismiss natural gas as unproven and impractical. Medium horsepower, commuter, and switcher locomotives are typically inefficient older units that are rebuilt every ten years. The low cost of rebuilding these units makes it difficult for the companies to justify investing in alternative fuels. The air quality districts that would fund upgrades to cleaner technology, won't fund kits or systems that have not been emissions verified. Until this cycle is broken these locomotives can be rebuilt over and over again with no reductions in emissions. Because these switcher, commuter and medium HP locomotives are mostly concentrated around urban areas, the emitted pollution directly affects large populations. The engine conversion is one barrier to locomotive natural gas use, the other is fuel storage safety and capacity. That second issue has a current EISG application submitted for a portion of the system, and will have a follow on PIER survey submitted in addition to this survey.

Initiative Description and Purpose

This initiative will start by developing and demonstrating in the test cell a Tier 4 emissions capable natural gas conversion of the existing EMD 645 two-stroke diesel locomotive engine. This testing will be performed on an 8 cylinder 645 locomotive test engine currently installed in ECI's test cell. This will require development and testing of spark ignited prechambers, diesel oxidizing catalyst, a modulated intake throttle and high mixing gas inlet valves. After the Tier 4 emissions levels are achieved, the system will be further developed with a Diesel Particulate Filter and Selective Catalytic Reactor system to achieve 'Near Zero' emissions. This will conclusively demonstrates the emissions capability and high efficiency of this system so that a multiple locomotive demonstration projects can follow. These follow on projects will include Tier 4 switchers, 'Near Zero' hybrid switchers and CNG/Hybrid commuter locomotives. The hybrid locomotive energy storage systems are proposed to be developed under a separate CEC ARFVTP funding plan survey.

Stakeholders

SoCal Gas, Metrolink, SCAQMD have all supported a similar program ending in the 1997 called GasRailUSA. CARB has tried to fund Medium HP Tier 4 locomotive demonstrations and would fund an actual demonstration on a locomotive, but the engine system has to be already verifiedfinished with test cell developement. Federal funding is unlikely to come from DOE as it has a focus on trucks and track record of not funding railroad technologies.

Background and the State-of-the-Art
Previously, the CEC PIER program funded Turbulent Jet Prechamber development with Michigan State University under contract 56620A/09-01G, this research is documented in SAE paper 2012-01-0823. In this prior program, a spark ignited prechamber system was designed, prototyped and operated in a small 83mm bore optical engine. This research validated a viable method for operating a spark ignited engine at very lean air fuel ratios resulting in very low NOx emissions and high thermal efficiency. In this testing, NOx levels 80% below Tier 4 were achieved. This current research proposal expands on that research to much larger diameter cylinders such as those in locomotives at 248mm diameter. In addition SwRI, SoCal Gas, Metrolink, SCAQMD participated in the 1997 GasRailUSA project performing single cylinder work on a larger 710 EMD locomotive engine. This is described in SAE paper 972967 'Evaluation of six natural gas combustion systems for LNG locomotives'. In this project SwRI also was able to achieve low NOx levels with spark ignited prechambers, but after minimal testing moved on to the other 5 gas combustion systems. The Napa Wine train has been operating one of its locomotives using and ECI prechamber system since 2001. This system is not certified to any emissions level and would likely only meet Tier 2 if it was tested. This system has proven the durability of the basic gas engine EMD conversion system, but is not using 'turbulent jet' prechambers or high mixing gas inlet valves.

Justification
The Tier 4 natural gas locomotive conversion is a stepping stone to a 'near zero' emissions locomotive system for use in switching and commuter applications. The Tier 4 locomotive system by itself will:
• Reduce NOx emission by 90%
• Reduce PM emissions 70%
• Reduce GHG emissions 25%
• Displace 50,000 gallons of diesel for each locomotive per year
• Save the operator 60% in fuel costs ~$ 75,000/year
When this system is combined with an SCR and hybridization it will result in:
• Near Zero CAC emissions
• Further 35% reduction in fuel use and GHG emissions
• 200% increase in acceleration
• Fuel saving and performance benefits to faster trains running more often
• Improved service leads to more revenue, more revenue leads to…
• Over 100 commuter locomotives in California and growing
• Metrolink alone would save $20million per year in fuel saving

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative (Short and concise):

92. Develop Natural Gas Engines that can meet the Near-Zero Emission Targets

Issues or Barriers

California's ozone non-attainment areas are not only the dirtiest in the nation but are also the most difficult to resolve. The state has yet to develop a State Implementation Plan (SIP) that demonstrates that either the South Coast Air Quality Management District (SCAQMD) or the San Joaquin Valley Air Pollution Control District (SJVAPCD) will reach attainment. Compliance is only going to get tougher should the Federal government ratchet down the National Ambient Air Quality Standard (NAAQS) for ozone to 65 parts per million (ppm) from the current NAAQS of 75 ppm. Complicating matters is the state's greenhouse gas reduction objectives, which in the short term appear achievable, but in the long term seek an 80 percent reduction from 1990 levels by 2050. For the state to meet the challenge of reducing both criteria pollutants and greenhouse gases, it must drastically reduce the environmental foot print of the transportation sector. On- and off-road vehicles and equipment are the source of nearly 90 percent of the ozone in the SCAQMD and a similar percentage of the problem in the SJVAPCD. To achieve these dramatic reduction targets, the Air Resources Board and local air districts have focused primarily on converting both on- and most off-road equipment to electric or fuel cell technology, or what is known as zero emission vehicles (ZEVs). Transitioning the mobile sector to ZEVs is no small task. As of this writing, there are only a handful of battery-electric light-duty vehicles that are commercially available, and there are no fuel cell vehicles that can be purchased in any weight class. Although industry experts believe that the light-duty sector holds a great deal of promise for such technologies, the heavy-duty on-road and the high horsepower sectors pose substantial technological and economic hurdles for such technologies. Alternatives to battery electric and fuel cells are needed that can achieve roughly the equivalent emissions but which rely on more conventional technologies to power heavy-duty vehicles and high horsepower equipment. What is needed is research, development, demonstration, and commercialization of near-zero emission engine technology for heavy-duty vehicles and high horsepower equipment.

Initiative Description and Purpose

The purpose of this initiative is to provide resources to engine and emission control equipment manufacturers to develop near-zero emission heavy-duty engines that can be used in Class 7 & 8 tractors and which can be used in high-horsepower off-road equipment, such as cargo handling, construction, drilling, mining, locomotives and marine vessels, to name a few. Such technologies would be designed to achieve NOx emission rates of no more than 0.05 grams per brake horsepower hour (g/bhp-hr) and 0.003 g/bhp-hr PM emissions.

Stakeholders
The primary stakeholders for this project are all of the owners, operators, and manufacturers of heavy-duty vehicles and high horsepower equipment. These stakeholders are facing increasingly stringent emission reduction requirements in the coming years and will need technology that can both perform the heavy-duty jobs and meet the demanding duty cycles of these sectors while still being affordable to both purchase and operate. The secondary stakeholders are all of the breathers in the State of California, as recent modeling clearly shows that the heavy-duty vehicle and high horsepower equipment sectors are rapidly becoming the largest sources of both NOx and PM emissions. Future emission reduction targets are clearly not achievable unless the state can eventually replace the rolling stock in these sectors with zero- and near zero emission technology.

Background and the State-of-the-Art
There is a great deal of interest in the development of near-zero emission heavy-duty engines. The continued high costs of battery electric and fuel cell technologies, particularly those that have been developed and are currently being demonstrated for the transit market, have stimulated interest in the creation of lower cost alternatives that can achieve similar emission reduction goals. This has brought attention to natural gas fueled engines, and how the utilization of the emission reduction technologies – which have been needed to enable diesel engines to achieve the 2007 and 2010 heavy-duty engines standards – can be used on this inherently cleaner fuel. If given a regulatory reason to do so, engine manufacturers claim that they can achieve remarkably low emission levels applying these state-of-the-art emission reduction technologies to natural gas engines; emission levels so low that they are the equivalent of a battery power vehicle charged from the California grid.

Justification
The emission reduction goals for both criteria and greenhouse gas emissions in the state of California are incredibly difficult. At the same time, the state has been suffering from a weak and underperforming economy for over a decade. Businesses are struggling, public agencies are sinking deeper in debt, and service providers who rely on heavy-duty vehicles – such as transit and refuse management agencies – are finding it more and more difficult to replace their rolling stock at a reasonable interval. Electric and fuel cell vehicle technology, and the recharging and fueling infrastructure necessary to enable these vehicles to work, are extraordinarily expensive. Lower cost alternatives that can achieve the same emission reductions, particularly those that hold the promise for long term cost savings from conventionally-fueled operations, can help cash strapped fleet owners and operators reduce the environmental footprint of their activities while maintaining or expanding service.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety

☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative (Short and concise):

93. Improved Efficiency for Heavy-Duty Natural Gas Engines

Issues or Barriers

New diesel engines have demonstrated exceptional improvements in fuel efficiency, with some over-the-road Class 8 tractor-trailers achieving greater than 8 MPG. This is a result of new USEPA 2010 diesel engines with SCR urea systems that allow for post-engine exhaust cleanup of NOx. Such fuel efficiency improvements are also, in part, a result of the application of various aerodynamic fittings on the tractor and trailer (i.e. SmartWay technology). In 2014, new USEPA regulations will further improve the efficiency of diesel engines, with some OEMs estimating an additional 2% to 3% increase in efficiency. At the same time, new natural gas powered trucks are showing fuel efficiency results in the 5 MPG to 6 MPG range with no increase in these efficiencies expected in the foreseeable future. This growing discrepancy in the fuel efficiencies of these two technologies presents a potentially significant barrier to the increased adoption of natural gas trucks as the economic arguments for this technology are eroded by the very high and impressive fuel efficiency gains made by diesel engines. It is therefore proposed that the Energy Commission allocate resources to improve the efficiency of heavy-duty natural gas engines and trucks in order that they are able to more effectively compete with today's modern diesel platforms.

Initiative Description and Purpose

Increasing the efficiency of heavy-duty natural gas truck / engine platforms can be achieved via on- and off- engine strategies - i.e. improving the efficiency of the actual engine, and also via the integration of natural gas engines into tractor-trailers equipped with the latest SmartWay technologies. For more local stop-and-go applications such as refuse trucks, transit buses and urban delivery trucks, increases in the fuel efficiency of natural gas engine platforms and heavy-duty vehicles can be achieved via hybridization of these platforms, in both mechanical (hydraulic) and electric means. The success of this effort will allow for the continued adoption of these increasingly popular 100% petroleum free alternative fuel technologies.

Stakeholders

Truck and engine manufacturers and end-use fleet customers all support this initiative.

Background and the State-of-the-Art

There have been one or two projects to hybridize natural gas engine platforms. These have been "one off" projects without the engagement of the heavy-duty engine and trucks OEMs. The results of these projects have not been well publicized, leading one to believe that they were not tremendous successes. The SCAQMD is interested in these issues, as they wish to further reduce the environmental footprint of heavy-duty engines and trucks. By increasing the efficiency / hybridizing these platforms, such results can be achieved. These OEMs are now more actively engaged in the heavy-duty truck market and will be very interested in a program of this nature.

Justification
The market penetration of petroleum free alternative fuel heavy-duty vehicle and engine technologies has begun to more rapidly increase in the last 12 to 24 months. With even more natural gas OEM products expected to hit the market in the coming 12 to 36 months, maintaining this increased market growth for these technologies is critically important for California to achieve its multiple progressive energy and environmental policies. Funding for a program to increase the efficiency of heavy-duty natural gas vehicles will allow for the continued market penetration of these petroleum free alternative fuel technologies as they will be able to more evenly compete against increasingly efficient diesel fueled trucks. The benefits of the increased market penetration of heavy-duty natural gas trucks are many, including:

- The immediate reduction in petroleum use and reduced reliance on imported oil;
- The increased use of clean domestic energy sources, which are more reliable than imported sources and superior from an economic development perspective;
- Reductions in criteria and toxic air containment emissions;
- Greenhouse gas (GHG) emissions reductions;
- The ability to convert to renewable non-fossil fuels; and,
- Lower fuel costs for end-users.

Specifically, the benefits that are achieved via the replacement of a heavy-duty diesel truck / bus / refuse collection vehicle with one powered by natural gas will be:

- Nitrogen oxide (NOx) emissions are reduced by up to 50% compared to 2010 diesel engines and even more compared to the older diesel engines being replaced;
- GHG emissions are reduced by over 21% compared to standard diesel trucks;
- GHG can be reduced by over 80% when using renewable natural gas; and,
- Every truck that is transitioned to natural gas eliminates the use of 5,000 to 30,000 gallons of diesel fuel per year, depending upon duty cycle.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative (Short and concise):

94. Research on repowering a certain vehicle or equipment to run on natural gas and testing

Issues or Barriers
Barriers to full market adaptation is the cost of the research and testing to see what engine would work and that the integration and adaptation is possible on the vehicle or equipment and testing with a lab.

Initiative Description and Purpose
The research and testing will allow knowledge on what engines and equipments can be repowered with natural gas engines.

Stakeholders
Businesses, vehicle and equipment owners, CNG component manufacturers and the general public since the fuel cost is almost half the cost of Gasoline or diesel and its clean for the environment.

Background and the State-of-the-Art
Currently there isn't a lot of data available on what natural gas engines can be repowered in vehicles and equipments that are currently used in the market. Research needs to be done in this field. Natural gas is abundantly available in the US and using the fuel will help reduce our dependence on foreign oil. Electric is also considered an alternative fuel however electric is still not viable as the cost of batteries is high and range issues, and long charging time still need work and there is still a lot of work needed to overcome these issues.

Justification
This research and testing will provide natural gas ratepayers benefit since they can run natural gas fuel in different vehicles and equipments.

- Sector sizes is all vehicle and equipment owners. There are companies who use up to 1 billion dollars worth of diesel fuel in running diesel engines and vehicles, imagine if that could use natural gas instead that could lower gasoline or diesel fuel dependency.
- The technology can be used within the transportation industry.
- Maximum market potential is huge; the market needs research in this field.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative (Short and concise):

95. Research technologies to convert existing gasoline engines to run on Natural gas, where it can be running on one or the other fuel separately.

Issues or Barriers
Barriers to full market adaptation is the anxiety of running out of natural gas and not having a station nearby but if there was technology where you could switch from natural gas to gasoline when needed that would cause users to adopt natural gas very quickly.

Initiative Description and Purpose
The technology will allow the natural gas to be used in existing engines.

Stakeholders
Business, fleet operators, agriculture businesses, farms, CNG component manufacturers and the general public since the fuel cost is almost half the cost of Gasoline or diesel and there would be no anxiety thinking about where the next natural gas station is. All these entities support the initiative.

Background and the State-of-the-Art
Currently there are converters that can add a system however there needs to be more work done in this field. The technologies are in the proof of concept stage and prototype state and need to go further to see what can be done. There are many incentives in California for funding alternative fuel but not enough for natural gas technologies on exiting engines. Natural gas is abundantly available in the US and using the fuel will help reduce our dependence on foreign oil. Electric is also considered an alternative fuel however electric is still not viable as the cost of batteries is high and range issues, and long charging time still need work and there is till a lot of work needed to overcome these issues.

Justification
This technology will provide natural gas ratepayers benefit since they can run natural gas in their existing engines.

- Sector sizes can vary with fleets, farmers, businesses and transportation delivery businesses. There are companies who use up to 1 billion dollars worth of diesel fuel in running diesel engines and vehicles, imagine if that can be cut by half by the fleets being able to use natural gas fuel.
- The technology can be used within the engine manufacturer industry
- Maximum market potential is huge; the market needs natural gas technologies to be used in existing engines.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety

☒Societal benefits
☐GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative (Short and concise):

96. Research natural Gas Engine technologies to produce natural gas engines at lower costs.

Issues or Barriers
Barriers to full market adaptation is the cost of natural gas engines. In the past lack of information was a factor as well but right now the cost of the natural gas engine needs to be decent for businesses and fleets to purchase them.

Initiative Description and Purpose
The technology will allow the natural gas engines to be produced at lower costs and will address one of the biggest issues.

Stakeholders
Business, fleet operators, agriculture businesses, farms, natural gas engine manufacturers, CNG component manufacturers and the general public since the fuel cost is almost half the cost of Gasoline or diesel. All these entities support the initiative.

Background and the State-of-the-Art
Currently there are very few natural gas engine manufacturers in the USA maybe one or two. They do produce engines however the cost is very high and it makes the overall purchase of a natural gas engine very expensive. There is research going on in this field however nothing has really been done to lower the cost of producing these engines. The technologies are in the proof of concept stage and need to go further to see what can be done. There hasn't been anything done in the industry yet to lower the cost of producing these natural gas engines. There are many incentives in California for funding alternative fuel but not enough for natural gas technologies or engines. Natural gas is abundantly available in the US and using will help reduce our dependence on foreign oil. Electric is also considered an alternative fuel however electric is still not viable as the cost of batteries is high and range issues, and long charging time still need research and there is still a lot of work needed to overcome these issues.

Justification
This technology will provide natural gas ratepayers benefit since they can purchase an engine at a lower cost than what is available now.

- Sector sizes can vary with fleets, farmers, businesses and transportation delivery businesses. There are companies who use up to 1 billion dollars worth of diesel fuel in running diesel engines and vehicles imagine if that can be cut by half if by the fleets being able to use natural gas fuel.
- The technology can be used within the engine manufacturer industry
- Maximum market potential is huge, the market needs a lower priced natural gas engine.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☐GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative (Short and concise):

97. Research technologies to convert existing port yard trucks to run on Natural gas

Issues or Barriers
Barriers to full market adaptation is the information for the port operators to realize that using natural gas is cleaner and that it is viable and it can be done.

Initiative Description and Purpose
The technology will allow the natural gas to be used in yard tracks at the port.

Stakeholders
Port operators, Businesses, CNG component manufacturers and the general public since the fuel cost is almost half the cost of Gasoline or diesel and its clean for the environment.

Background and the State-of-the-Art
Currently there aren't any natural gas engines that can be adapted to the port yard trucks. Research needs to be done in this field. Natural gas is abundantly available in the US and using the fuel will help reduce our dependence on foreign oil. Electric is also considered an alternative fuel however electric is still not viable as the cost of batteries is high and range issues, and long charging time still need work and there is till a lot of work needed to overcome these issues.

Justification
This technology will provide natural gas ratepayers benefit since they can run natural gas in the yard trucks.

- Sector sizes is all the ports in USA. There are companies who use up to 1 billion dollars worth of diesel fuel in running diesel engines and vehicles, imagine if that could use natural gas instead that could lower gasoline or diesel fuel dependency.
- The technology can be used within the port industry.
- Maximum market potential is huge; the market needs natural gas technologies to be used in these yard trucks. To cut out all the soot and emissions that are emitted at the ports.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative:

98. Nano-Valved Adsorbents for Natural Gas Vehicles

Issues or Barriers

Most natural gas vehicles (NGV) today employ only basic storage technologies—90% of vehicles still use Type I tanks (low cost steel tanks) and engines simply use modified gasoline and diesel engines. Type IV light-weight carbon fiber composites tanks have gained popularity in the U.S. While Type IV tanks have superior specific energy densities to steel tanks, they cost about four times more—primarily due to the cost of carbon fiber. Even at attractive residential natural gas prices relative to gasoline, current technologies are unable to meet the stringent price and performance metrics required for the adoption of light-duty NGV. The capability of storing natural gas at the equivalent density achieved by compressed natural gas (CNG) vehicles at 250 bar at an operating pressure of 35 bar would help improve the adoption of NGV.

Initiative Description and Purpose

We propose to develop nano-valved adsorbents for reversible CH4 storage. The nanovalved sorbents comprise of a molecular sieve layer or amorphous nano-porous layer coated on the outer surfaces of the adsorbent pellets. The nano-pores of the coating layer function as valves that can be opened and closed on demand. Loading occurs at high pressures (~250 bar) with the nano-valves open. The nano-valves are closed when the adsorbents are fully loaded. Loaded adsorbents can then be stored at low pressures (~10 bar), and the nano-valves can open again for releasing the stored CH4. The opening and closing of the nano-valve is controlled by the amount of adsorbate adsorbed in the pores of the coating layer, which can be accomplished by adjusting the activity of the adsorbate during loading and by controlling the temperature of the sorbent system during the release of natural gas. The required strength and resulting weight of the storage tank is greatly reduced.

Stakeholders

The implementation of this technology would accelerate the commercial viability of NGV. Increasing the number of NGV through the development of this technology would benefit the State of California by reducing hydrocarbon and green house gas emissions. The consumers would benefit by having economical NGV available for their purchase choice. The natural gas pipeline industry would benefit from increased market demands. The State of California funds would be leveraged by DOE's ARPA-E program funds already in place under their MOVE program.

Background and the State-of-the-Art

While high surface area materials, such as zeolites, metal-organic frameworks (MOF), covalent organic frameworks (COF), activated carbon, and carbon nanotubes have shown promise for CH4 storage, their capacities at 35 bar of <8 MJ/L and 0.3 g CH4/g sorbent are much lower than DOE targets of volumetric: 12.5 MJ/L, gravimetric: 0.5 g

CH4/g. The use of Nano-Valved adsorbents would reduce the weight and cost of the NGV fuel tank.

Justification
In California, the natural gas use for transportation section is less than 1% implying considerable market potential. Natural gas vehicles can reduce pollution and greenhouse gas emissions generated by most vehicle sources, from commuter traffic to delivery trucks and refuse haulers to port trucks. According to a November 2008 study by the Institute for Economic and Environmental Studies at California State University, Fullerton, air pollution in Southern California and the San Joaquin Valley alone costs California $28 billion a year. Owing to its huge economy, the state is the 12th largest emitter of carbon in the world. Natural gas vehicles will also help reduce California's oil dependence.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative

99. CNG Engine - Hybrid Medium and Heavy-Duty Truck Demonstrations

Issues or Barriers
The energy efficiency and emissions reduction benefits of hybridization of a vehicle's power train system have not been translated from the recent successes in light duty gasoline platforms to medium & heavy-duty vehicles using natural gas. Furthermore, there are applications for medium & heavy-duty vehicles that could overcome operational challenges of high power low torque requirements for short durations (such as drayage trucks or ramp climbing) or severe stop and start drive cycles (shuttle bus or refuse collection) that could benefit from the use of a short term energy recovery and storage technology (hybridization).

Initiative Description and Purpose
Develop and demonstrate an Advanced Hybridization CNG-Battery Bus or Medium-Heavy Duty Trucks. Hybrid technologies could dramatically reduce emissions, noise, and fuel use while yielding both operational longevity and cost benefits to the industry. Advanced hybridization technologies have been successfully applied to conventional fueled engines in several light duty applications, however a CNG-electric Hybrid and/or Plug-in CNG hybrid, and/or CNG Hydraulic hybrid technologies applied to medium and/or heavy duty bus and/or truck platforms could show great value to the owner/operator if first cost could be brought down.

Stakeholders
USDOE, AQMDs, Sempra, SoCal Gas, Public & Private Fleet Operators, Engine Manufacturers, Truck OEMs, Battery Manufacturers, Vehicle Integrators

Background and the State-of-the-Art
In-service and test results for hybrid diesel buses shown encouraging results. The operators expect 90% reductions in PM, CO, and HC emissions, 40–60% reductions in CO2, and 50% reduction in NOx versus conventional diesel buses. By applying similar reductions through reduced fuel use to an inherently cleaner natural gas engine-based vehicle platform, these technologies will be approaching near zero emissions in some duty cycles of operation. The primary components to a medium or heavy-duty hybrid vehicle are commercially available, however integrating them into a platform that takes full advantage of the space and weight differences, plus optimizes the system for the expected duty cycle, is the remaining challenge and should be the focus of a technology demonstration program.

Justification
Medium & Heavy-duty vehicles account for 9% of GHG emissions in California. GHG's from these classes of vehicles have up to a three times higher growth rate than the corresponding growth rate for light-duty vehicles. Medium-and heavy-duty vehicles consume over 18 percent of the total fuel used in California's vehicle fleet. These

vehicles also emit more toxic air pollutants on a per gallon fuel consumed basis than light duty vehicles. Since operators of diesel hybrid buses report fuel savings of 30–40%, expected maintenance savings of 30 –50%, and high reliability, these same attributes out of a natural gas engine-based vehicle should make the technology cost effective for the user once product is developed. The reasons for these savings come from:

• Smaller engines, in parallel systems where the reciprocating engine and the electric motors share the load, allowing use of smaller more fuel efficient engines to do the work of larger horsepower straight drive systems.

• Hybrids have sophisticated engine management systems to balance the load and maximize efficiency. Gas hybrids may facilitate use of instant start systems to shut the engine down at stops or whenever it is not needed.

• Reduced friction losses can be realized from less dependence on mechanical transmissions and differentials, hence reducing the potential for the inherent friction losses.

• Regenerative braking through turning the traction motors into generators and using the vehicle's momentum to produce electric power while braking, hybrid vehicles can use part of the kinetic energy to charge their own batteries. Some vehicles have reportedly recaptured as much as 40% of the energy they needed to operate.

Ratepayer Benefit (Check one or more.)

☐Promote greater reliability
☐Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative

100. Late State Development, Demonstration & Product Launch of Class 3-7 Med Duty Vehicles

Issues or Barriers

CEC PON 12-504 was recently issued to demonstrate promising technologies that advance the performance, fuel efficiency, and competitiveness of natural gas engines, based on existing gasoline and diesel engines of approximately 6 – 8 liters displacement suited to power Class 3 – 7 vehicles. Following successful completion of an alpha new engine development funded under PON 12-504, it will be critical that CEC solicit and fund a follow on opportunity to expand on the alpha engine design deliverables and complete a full product development, demonstration and commercialization program.

Initiative Description and Purpose

The goal of this proposed research idea is to complete the product development process of a new Class 3-7 alpha engine resulting from CEC PON 12-504. The product development would include testing, emissions certification, and commercialization activities to accelerate market introduction and penetration of advanced natural gas engine concepts for application in light heavy-duty vehicles (LHDV) and medium heavy-duty vehicles (MHDV) operated in fleets throughout California. To achieve commercial availability of the technology resulting from CEC PON 12-504, the required steps include:

- Product development including creating designs for engine hardware, electronic control and ignition systems, and performance and emissions calibrations.
- Testing the engine and component designs using test rigs, laboratory facilities, engineering vehicles, and customer vehicles, to evaluate and refine the component and engine designs and electronic and control system calibrations.
- Identifying and validating production suppliers for all engine components, and conduct alpha and beta engine builds at the engine manufacturing plant.
- Releasing all engine specifications so that customers can order engines and the engine plant to begin order components from production suppliers.
- Conducting all required emission testing necessary to obtain EPA and CARB emission certification.
- Providing detailed engine specifications and performance information to vehicle OEMs to support timely and high quality engine/vehicle integration work.

Stakeholders

Sempra, SoCal Gas, AQMDs, fleet owners and operators of Class 3-7 vehicles, Class 3-7 engine OEMs

Background and the State-of-the-Art
At least one US manufacturer, Cummins Westport Inc, has developed and commercialized a heavy duty, 8.9 liter natural gas engine and is currently in the product development stage to introduce an 11.9 liter engine. The 11.9 liter engine was scaled up from the 8.9 liter version. Developing a new engine to serve the Class 3-7 market should be a relatively low risk program that can make a significant impact in the marketplace within 2 years.

Justification
According to the CEC NGV Research Roadmap, over the next 5–10 years, it can be expected that medium-duty vehicles (MDVs) and HDVs—primarily HDV refuse trucks and buses, will continue to be the dominant classes for NGV applications. Vehicle integration is a significant hurdle to greater NGV availability and market penetration. The Roadmap further states "Original equipment manufacturers (OEMs) are generally unwilling to allocate engineering resources to design the integration of natural gas engines into new chassis without assurance of product sales. The high cost of developing and certifying a new NGV model is also a significant hurdle to broadening NGV options for on-road and off-road applications. This gap could be resolved by offering cost-sharing incentives to OEMs for natural gas engine integration, leading to more chassis options for existing engines".

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative

101. Compressed Natural Gas Fueling Station Infrastructure Capital Cost Reduction

Issues or Barriers
There are some 1,200 compressed natural gas (CNG) fueling stations nationwide and over 100,000 retail gasoline stations. The disparity in number of station is predominately due to large differential in capital cost associated with station construction leading to weak return on investment into such infrastructure. The average public retail CNG station capital cost ranges from $300,000 to over a $1,000,000 to build in comparison to $40,000 for its gasoline equivalent station.

Initiative Description and Purpose
Funding is required to investigate all aspects station design and construction including moisture content control, natural gas compression, natural gas storage, and dispensing. Advancements in CNG station operations and technologies can reduce the capital costs while maintaining the high degree of safety associated with CNG as a vehicular fuel. Industry partners providing equipment, installation, operations, and maintenance each have ideas for ways to drive down costs and lower the overall cost of ownership of natural gas vehicles. A broad based funding opportunity that could support the best proposals for near term CNG station cost reductions would certainly attract technology and/or operations improvements for CEC's consideration.

Stakeholders
Sempra, SoCal Gas, USDOE, CNG Station Owners/Operators, & CNG Vehicle Owners

Background and the State-of-the-Art
There has been research started and ongoing to advance compressor technologies enabling improved durability and reliability, hence reducing operating costs. There is ongoing research regarding natural gas storage in larger quantities and/or at lower pressures (Absorbed Natural Gas (ANG)) and at reduced costs. USDOE has renewed interests in ANG contributing close to $10 million dollars in 2012 through its ARPA-E initiative aimed at the advancement of this technology alone. The cost of moisture removal equipment to properly condition the incoming natural gas stream to a fueling station adds significant enough cost that more cost effective alternatives are worth exploring.

Justification
Station owners will benefit from a reduction in initial capital investments further improving payback periods and increasing rates of return on their investments. CNG vehicle owners will benefit from lower cost CNG at the pump, and rate payers and residents of California will benefit from improved air quality and greater freedom in transportation fuel choices.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☒Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative

102. Guidance Document for Pipeline Injection of Renewable Natural Gas

Issues or Barriers
Vehicle fuels produced from Renewable Natural Gas (RNG) have the lowest Carbon Intensity Vales (CIV) of any fuel pathway. The largest barrier impeding the wide-spread use of anaerobic digestion and landfills for the production of vehicular fuel is the fact that it is a near impossibility to balance the constant production of RNG (or bio-methane) with the varying fleet demand for fuel. This leads to systems that need to flare RNG or invest in massive storage vessels that are cost prohibitive because injection of the RNG into utility-owned natural gas pipelines has significant uncertainty and cost projections that can be prohibitive.

Initiative Description and Purpose
CPUC regulations allow for injection of some RNG into the pipeline but it has proven to be difficult and costly to pursue. An evaluation of this process along with a published guidance document would decrease market risk for investors and provide guidance that could significantly reduce the engineering and equipment costs specified for future installations.

Stakeholders
Sempra, SoCal Gas, USDOE, Water Treatment Plants, Landfills, Ag Waste Producers, Dairy Farmers, AQMDs

Background and the State-of-the-Art
There are very few locations in California where pipeline injection of RNG has been successfully implemented even though there is substantial market interest. These large-scale solutions are currently available but the renewable fuel is typically vented to atmosphere, flared or in the current best case scenario is used in low value added applications such as providing fuel for a boiler in winter months. Some large dairy-waste and municipal solid waste facilities have attempted pipeline injection but they have often abandoned installations because of regulatory and costs issues.

Justification
Resource potentials for bio-methane is approximately 2,000 MW in California (Source: B&V & SMUD 2010, *A case of biogas for Pipeline* Injection). These renewable energy sources have the potential to significantly reduce greenhouse gas (GHG) emissions and petroleum fuel demand, and stimulate economic development in the state. This relatively low-cost initiative would allow for a significant increase in the use of RNG for transportation fuels.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs

☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative (Short and concise):

103. Natural Gas Intestine Packed Storage Tank

Issues or Barriers
Natural gas is less expensive, releases less CO2, and has more domestic sources than gasoline, yet NGV's (Natural Gas Vehicles) have yet to enter the mainstream light duty automotive market. We believe this lack of widespread adoption is primarily due to high system cost, increased weight, increased cost, and lack of conformable tank designs.

Initiative Description and Purpose
In the design of a cylindrical tank the ratio of the tank mass to the contained gas mass is not dependent on tank geometry. The mass of the material used, and thus the bulk material cost is constant for a given pressure and material yield stress. With no penalty paid (in material cost or packing density) for moving to small diameter tubes we gain the ability to fit the tank into any 3D shape desired - for example embedded in the chassis of the vehicle as an intestine-like storage unit. We propose development of a small diameter, densely packed, tube based, conformable CNG tank. This tank will lower tank costs, and decrease total weight, while allowing more flexibility in integrated NGV design. This project is a continuation of a research project funded by the US Department of Energy. This company is looking for additional funding to take technology researched in the first stage of this project to market. This involves exploration of large-scale manufacturing techniques as well as product-specific designs for vehicle fuel tanks.

Stakeholders
Natural gas is a strategic resource, since it is a fuel that can be readily sourced in the United States. Expanding the fraction of the automotive market that runs on natural gas will benefit domestic natural gas companies and reduce our dependence on foreign energy sources. Additionally, creating a domestic edge in NGV's will give domestic car companies and edge over the foreign car manufacturers. Finally, replacing carbon-intensive petroleum-based fuel with CNG in the public and private US transportation infrastructure will significantly lower the carbon footprint of the US economy. The US Department of Energy has identified these as strategic goals and has funded the first stage of this company's Natural Gas Intestine Packed Storage Tank research program with $250,000.

Background and the State-of-the-Art
Several automotive companies, including Ford, Fiat, and Honda, have released CNG vehicles in the past 10 years, yet CNG storage solutions are still bulky and expensive cylinder based systems. GM and Fiat both have designs in which various sized cylindrical tanks are integrated into the vehicle chassis design. Many conversion kits exist, though these suffer from even more issues associated with cost and space than the integrated systems. Carbon fiber tanks are beginning to enter the mainstream which

reduces the weight of NG systems. However, their packability remains limited by packing density as the weight of the tanks approach the weight of the compressed gas.

Justification
The number of vehicles in California is greater than 33 million (US DOT, 2006) with only about 14,000 being NGV's (GVR, 2012, proxy number computed by scaling US-wide figure to CA GSP). That is only .04% of the vehicles in the state are currently NGVs. With DOE goals upwards of 20% NGV nationally by 2020 (Annual Energy Outlook, 2012), California's growth in this sector will exceed 100% CAGR over the next 8 years, adding 6 million new NGVs until 2020. The total 2020 market size in California alone will be $6B, the US domestic market is $250B in size, assuming all vehicles are converted to CNG. DOE targets suggest at least 20% of that market is likely to be addressed in 2020.

Ratepayer Benefit (Check one or more.)
Lower costs - check
Increased safety- check
Economic development - check

Name of Initiative:

104. Advanced Natural Gas Fuel Tank – Low pressure Storage

Issues or Barriers
Low pressure natural gas adsorption, ANG, has additional costs, namely the cost of dealing with varying adsorption forces for different gases, the cost of methane detection, a guard bed and dealing with natural gas contaminants. Preliminary cost benefit analysis showed that the effect of the thin walled pressure vessel and smaller compressors may be enough to offset the cost of methane detection, a guard bed and dealing with natural gas contaminants.

Initiative Description and Purpose
Develop low pressure natural gas storage tank. ANG has two main benefits over CNG; the benefit of less-expensive, thinner-walled pressure vessels and the benefit of less-expensive, smaller compressors.

Stakeholders
DOE, SCAQMD, SCG

Background and the State-of-the-Art
The current technology achieve the DOE's goal of storing 180 cubic feet of standard temperature and pressure natural gas in a 1 cubic foot tank at only 500 psi. The future technology needs to be developed is improved carbon adsorbent and improved tank design that is reasonably affordable and exploits the benefits of adsorption and an improved carbon adsorbent.

Justification
- Advance Technology development
- Minimize technological barrier incumbent
- Less expensive alternative to gasoline or diesel
- Alternative to gasoline or diesel that can be supplied with domestic reserves
- Environmentally friendly alternative to gasoline or diesel
- Safer alternative to high pressure compressed gas
- Higher energy density of natural gas vehicle supply tanks

Ratepayer Benefit (Check one or more.) X Promote greater reliability
X Lower costs
X Increased safety
X Societal benefits
X GHG emissions mitigation at the lowest possible cost
☐ Economic development

Name of Initiative:

105. Home Refueling Appliances (HRA)

Issues or Barriers

Low cost HRA is the next technology advancement that would help drive the natural gas vehicle market in State of California, help reduce overall emission and less dependent on import energy (i.e. petroleum). Due to the required operating condition, technical as well as practical feasibilities (size constraint) are among the challenges to develop low the cost installation. In order for a next-generation HRA to have very broad-based adoption in the light duty vehicle market, it will most likely need to be close to the price targets set by AGA/ANGA, which is $1.00 per GGE lifecycle cost of fueling (excluding the cost of natural gas but including the installation cost and amortization of development and start-up costs) for a 0.5 GGE per hour device. Based on the industry study, this appears to be a very difficult challenge for any of the technologies currently in “Production”.

Initiative Description and Purpose

Research on low cost HRA strategies (technology and manufacturing) that provide reliability and safe performance is needed to help drive the market adoption of natural gas vehicles. The availability of a residential home refueling and individual fleet vehicle refueling device would provide a complement to the growing public fueling and private fleet fueling infrastructure in North America and expand the use of light-duty natural gas vehicle (NGV). A cost effective option to enjoy the convenience of unattended fueling while parked at home or work has long been sought after. To make a significant impact in expanded home fueling such a device needs to provide worry-free, reliable, and safe performance and be backed by a stable support network.

Stakeholders

DOE, SCAQMD, SCG, NREL

Background and the State-of-the-Art

Currently, the BRC Phil is the only HRA available in the US market and its cost is more than double of the AGA/ANGA target. Based on the analysis performed by AGA and GTI, there does appear to have a few strong contenders could bringing a product to the U.S. market quickly, but with little promise for cost savings at the targeted levels.

Justification

The combination of stable, lower natural gas price levels along with an expectation of continuing (and increasingly divergent) oil-natural gas price differentials creates an unprecedented and compelling economic case for NGVs, especially if a low cost home fueling device is available to the marketplace. Recent analysis shows a strong business case of less than a 3 year payback can be made for a light-duty vehicle traveling only 13,000 miles per year achieving 22 miles per gallon with the current price spread between gasoline and natural gas, if a small capacity fueling device could be purchased

and installed for less than $2,000. If the low cost HRA is achieved, it has a major benefit to companies that have fleet transportation. Companies can install small modular system to fill their fleet vehicle at their facility rather than driving to a filling station.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative:

106. Systems for On-Board Natural Gas Storage and At-Home Refueling

Issues or Barriers
Current natural gas delivery systems for transportation are centrally located, require storing large quantities of compressed natural gas for volumes of vehicles and are relatively inefficient.

Initiative Description and Purpose
Fully integrating a natural gas vehicle (NGV) refueling compression system into the vehicle will transform the design of a NGV giving it the capability to refuel at any home or business where natural gas is present. The combination of NGV redesign and 'vehicle centric' refueling will provide the technological and economic drivers to increase the penetration of NGV's into the light duty vehicle market. Proof-of-concept demonstration will illustrate the advantages of the advanced design of the compressor, the incorporation of the compressor with the vehicular engine and the ability to refuel at home, all of which will expand use of natural gas as transportation fuel and increase customer satisfaction.

Stakeholders
DOE, SCAQMD, Southern California Gas Company

Background and the State-of-the-Art
The current systems utilize compressors, storage vessels, and pressurized gas transfer technology. Use of natural gas as the compressor fluid, the vehicle engine as the pump source of power and refueling at home are advantages currently unavailable. Initial design, fabrication and operation of the pump is necessary to satisfy correlation with the thermodynamic predictions and verify the planned operations. Operational testing to verify life and durability will provide the basis from which commercialization can be projected.

Justification
There are several benefits from the successful demonstration of this concept. It will offer the customer the ability to refuel at home, or to refuel virtually anywhere where the natural gas pipeline infrastructure exists. This concept will reduce the need for large scale infrastructure upgrades to current refueling stations.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative:

107. Improve Engine Efficiency Technologies

Issues or Barriers
Internal combustion engine technologies are likely to be the dominant propulsion systems for decades to come. Fuel economy can be dramatically improved in the light- and heavy-duty sectors through the advancement and application of existing and new technology.

Initiative Description and Purpose
To identify and develop key technologies for the development of high-efficiency, natural gas engines with low exhaust emissions, such as,

- Leverage liquid ICE fuel economy technology
- Combustion optimization
- Dedicated EGR engine
- Improved ignition sources
- High energy ignition
- Long life ignition sources (including spark plugs)
- Fuel Energy Recovery
- Fuel pressure recovery for CNG
- Combustion system designs
- Advanced controls
- High BMEP engines
- Other high efficiency concepts
- Gas engine specific architecture
- Heavy duty engine with a light duty gasoline like combustion chamber
- Novel high efficiency concepts

Stakeholders
DOE, SCAQMD, SCG

Background and the State-of-the-Art
Reciprocating engines are a widespread, well-known, and mature technology. Significant research and development efforts are underway to continue to improve the efficiency and reduce the emissions of reciprocating engines. Two significant programs in the past ten years were the Advanced Reciprocating Engine Systems (ARES) and the Advanced Reciprocating Internal Combustion Engines (ARICE) programs.

Justification
Improve economics
Reduce energy consumption and improve Energy Security
Reduce GHG
Reduce criteria emissions

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative:

108. Hybrid CNG-Battery Bus or Trucks

Issues or Barriers
Medium & Heavy-duty vehicles account for 9% of GHG emissions in California. GHG's from M HD Vehicles have up to a three times higher growth rate than the corresponding growth rate for light-duty vehicles. Medium-and heavy-duty vehicles consume over 18 percent of the total fuel used in California's vehicle fleet, about 3.7 billion gallons annually CEC projects 42 percent increase in demand for Diesel Fuel. These vehicles also emit more toxic air pollutants on a per gallon fuel consumed basis than light duty vehicles.

Initiative Description and Purpose
Develop and demonstrate an Advanced Hybridization CNG-Battery Bus or Trucks. Hybrid technologies could dramatically and permanently reduce emissions, noise, and fuel use while yielding both operational and cost benefits to the industry. *Advanced hybridization*: CNG-electric Hybrid, Plug-in CNG hybrid, and CNG Hydraulic hybrid

Stakeholders
DOE, SCAQMD, SCG

Background and the State-of-the-Art
Hybrid passenger cars are increasingly popular and hybrid pickups and SUVs have been introduced. Their success has increased public awareness and acceptance of hybrids.
In-service and test results for hybrid diesel buses shown encouraging results. Operators report fuel savings of 30–40%, expected maintenance savings of 30–50%, and high reliability. The operators expect 90% reductions in PM, CO, and HC emissions, 40–60% reductions in CO2 , and 50% reduction in NOx versus conventional diesel buses.

Justification
Operators of hybrid buses report fuel savings of 30–40%, expected maintenance savings of 30 –50%, and high reliability.
• Smaller engines. In parallel systems the reciprocating engine and the electric motors share the load, allowing use of smaller more fuel efficient engines. For example, ISE diesel hybrid buses use a 5.9 liter Cummins ISB engine rather than the larger, more typical Cummins ISM. In series systems the reciprocating engine only supplies electricity to the batteries or electric motors and can be significantly smaller or use different fuels.
• Engine management systems. All hybrids have sophisticated engine management systems to balance the load and maximize efficiency. Gas hybrids may facilitate use of instant start systems to shut the engine down at stops or whenever it is not needed.
• Reduced friction losses. Reduced dependence on mechanical transmissions and differentials reduces the potential for the inherent friction losses.

• Regenerative braking. By turning the traction motors into generators and using the vehicle's momentum to produce electric power while braking, hybrid vehicles can use part of the kinetic energy to charge their own batteries. Some vehicles have reportedly recaptured as much as 40% of the energy they needed to operate.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☐Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative:

109. Hybrid CNG-Battery Light Duty Vehicles

Issues or Barriers

- Providing adequate fuel storage is a challenge in most NGV conversion applications, and this challenge is exacerbated in hybrid vehicles due to their battery requirements.
- Multiple CNG cylinders add to NG system cost penalty.
- Unresolved NGV refueling infrastructure costs/issues.
- NGHV economics (fuel savings payback, depreciation, resale, etc.)
- Cylinder inspection/replacement schedules/costs/enforcement responsibility.

Initiative Description and Purpose

South Coast Air Quality Management District (AQMD) is an extreme non-attainment area tasked by EPA with daunting clean air mandates. Near-zero tolerance for environmental pollutants and minimization of fossil fuel use have become mantras of AQMD administrators and civic leaders.

Natural gas vehicles (NGVs) can and should play a role in an ultra-low emission solution for this region.

Develop a NG-electric hybrid powertrain configuration (possibly incorporating "plug-in" capability), and will provide a minimum driving range of 250 miles based on EPA combined city-highway fuel economy. Emissions will satisfy CA's PZEV standards.

Stakeholders

SCAQMD, SCG

Background and the State-of-the-Art

Hybrid passenger cars are increasingly popular and hybrid pickups and SUVs have been introduced. Their success has increased public awareness and acceptance of hybrids.

Justification

SCAQMD and CARB have recognized that investment in cleaner and more efficient transportation solutions will provide significant returns in terms of air quality and reduction in fossil fuel consumption.

Operators of hybrid vehicles report fuel savings of 30–40%, expected maintenance savings of 30 –50%, and high reliability.

- **Smaller engines.** In parallel systems the reciprocating engine and the electric motors share the load, allowing use of smaller more fuel efficient engines.
- **Engine management systems.** All hybrids have sophisticated engine management systems to balance the load and maximize efficiency. Gas hybrids may facilitate use of instant start systems to shut the engine down at stops or whenever it is not needed.

- **Reduced friction losses.** Reduced dependence on mechanical transmissions and differentials reduces the potential for the inherent friction losses.
- **Regenerative braking.** By turning the traction motors into generators and using the vehicle's momentum to produce electric power while braking, hybrid vehicles can use part of the kinetic energy to charge their own batteries.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☐Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative:

110. Near Zero Emissions Vehicles – Heavy Duty Transit Buses

Issues or Barriers
In February 2000, the California Air Resources Board adopted the Fleet Rule for Transit Agencies which includes a requirement that larger transit agencies begin to purchase zero emission buses. This zero emission bus purchase requirement was originally scheduled to begin in 2008, but only after a demonstration phase in which participating transit agencies procured and successfully operated qualifying buses. The two primary technologies which were expected to meet the zero emission bus requirements are hydrogen fuel cells and electric batteries. Even after one round of demonstration projects, these technologies are still extremely expensive, have low reliability and require costly operating and maintenance (particularly in the case of procuring hydrogen for fuel cell buses). From the demonstration project it appears that it will take at least several more years for zero emission technologies that meet the transit agencies operational needs to become reliable and cost effective.

Initiative Description and Purpose
Develop and demonstrate near zero emissions buses in California metropolitan areas. The vehicle emissions level should be equivalent to the best power plant operated in the California. The well to wheel emissions of the vehicles should be equivalent to electric or fuel cell vehicles.

Stakeholders
DOE, SCAQMD, MTA, SCG

Background and the State-of-the-Art
DOE, CEC, SCAQMD and SCG are cosponsoring this company to working with Doosan, and Woodward to develop the next generation natural gas engine. SwRI's technology has been shown to improve the EGR tolerance in spark ignition engines, which significantly increases the benefits that can be realized by the use of cooled EGR. The presence of a TWC and stoichiometric exhaust has been shown in previous applications to result in near-zero emissions of NOx, CO, HC and PM in pre-mixed engines. CEC, SCG and Kenworth are cosponsoring Brayton Energy to develop and demonstrate a commercially viable Class 8 alternative fueled vehicle utilizing a 350kW high efficiency, low emissions, multi-fuel ICR microturbine and hybrid power train technologies. The vehicle is expected to meet the 2007 CARB DG requirements (near zero emissions). SCG has discussed with Cummins Westport to develop a near zero emissions engine for transit applications. Westport believes it can be done with their existing ISLG 8.9 engine and an advanced catalytic system.

Justification
While we wait for the maturation of these zero emission buses, there exist other fuel choices and technologies that could provide significant emission reductions from

California's transit buses at a cost that transit agencies can afford today. Natural gas offers a considerable reduction in greenhouse gas emissions, oxides of nitrogen and particulate matter emissions than their diesel counterparts. We believe advanced combustion technology, hybrid technology, renewable natural gas and advanced after-treatment can further reduce oxides of nitrogen and greenhouse gas emissions from today's transit buses. These are lower cost technologies that can provide near zero emission levels.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative:

111. Novel Onboard Natural Gas Reforming for PEM Fuel Cell Vehicles

Issues or Barriers: The present PEM Fuel Cell Vehicles are designed to operate on stored high-pressure hydrogen. However, the hydrogen supply infrastructure is woefully inadequate to support widespread use of these vehicles. The current plan to install hydrogen refueling stations throughout specific locations within California is confronted with several obstacles, including locations, cost, size, regulations, and period of time over which these vehicles will become readily acceptable for widespread use.

Initiative Description and Purpose
In order to take advantage of the natural gas distribution infrastructure that is readily accessible, storage of natural gas onboard a fuel cell vehicle that is capable of converting the natural gas to a hydrogen-rich feed would allow introduction of fuel cell vehicles much sooner and over a wide range of customer-base. Compact, efficient, responsive fuel processor onboard fuel cell vehicles will allow fuel cells to be used as a plug-in battery hybrid vehicle, and offer the opportunity for these vehicles to serve as emergency electricity generators, using the widely available natural gas.

Stakeholders
Fuel Cell Manufacturers, Hydrogen suppliers

Background and the State-of-the-Art
To date, efforts to pursue onboard fuel processing for PEM fuel cells has ceased because of the inability to illustrate adequate efficiency and ease of operation. At the present time, hydrogen is stored onboard vehicles, typically at 10Kpsi, and needs a supply of high pressure hydrogen supply stations. Natural gas is readily available and the commonly stored pressure of natural gas (3Kpsi) provides a source of four hydrogen molecules for every methane molecule stored. All the previous approaches to producing hydrogen onboard a vehicle were directed toward the use of either methanol or gasoline and not natural gas. In addition, all investigations and demonstrations utilized currently used processes with some radical design adaptations. In order to take advantage of the availability of natural gas, facilitate the acceptance of storing the gas onboard the vehicle, and promote the use of fuel cells in transportation vehicles, onboard reformation of natural gas should be explored. One novel approach to this is to utilize a non-thermal plasma technology to provide onboard conversion of natural gas to hydrogen. This type of system has not been demonstrated at this time and requires a proof-of-concept effort to determine its value, a system design, and the timeframe required to bring this approach to viable commercialization.

Justification
Successful implementation of onboard reforming of natural gas for PEM fuel cell vehicles will expand the use of natural gas into the current use of petroleum-based fuels, thereby reducing the dependence on foreign imports. This would apply to both

gasoline and diesel fuel vehicles, resulting in a broad use of the technology and a benefit to natural gas utilization. Because the fuel cell is more efficient than IC engines, an overall reduction in fuel use would result and GHG emissions would also be reduced per traveled mile. This means of hydrogen production from natural gas could also be implemented in stationary electricity generation operations and provide additional benefits to consumers.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative:

112. Hydrogen-CNG

Issues or Barriers
Research on the use of H2 as a transportation fuel has proceeded separate from the development of compressed natural gas vehicles. Though, H2 and CH4 are closely related. CH4 is an economically viable transportation fuels today. CH4 has a distribution network in place today. H2 distribution pipelines are very rare. The most common source of hydrogen is large refinery-based steam-methane reformers. The connection between CH4 and H2 needs to be exploited in order to take advantage of the markets and distribution network available today to lead to a H2 economy of tomorrow.

Initiative Description and Purpose
This initiative will demonstrate two forms of distributed, small scale reformation:

1. Reformation of renewable hydrogen into methane, and

2. Reformation of renewable and conventional natural gas into hydrogen

Thus, at the production end renewable electricity produced form either photovoltaic panels or wind turbines will be used to produce hydrogen which will in turn be reformed into renewable natural gas. And the consuming end, methane will be converted into hydrogen for fuel cell powered vehicles.

Stakeholders
DOE, CARB, SCAQMD, SCG, and industry partner(s)

Background and the State-of-the-Art
A majority of the H2 in the US is created from a thermo-catalytic process called steam-methane reforming. This process emits CO2. Fuel cells for converting H2 to electricity are commercially available. Cars that can use H2 as a transportation fuel are not commercially available. There are very few pipelines for transporting H2. Generating renewable H2 from water or biomass for the production of renewable natural gas provides for development of hydrogen generation using the renewable natural gas markets of today. And the reformation of methane into hydrogen on a small scale at points of distribution will enable the proliferation of hydrogen fuel cell vehicles.

Justification
- Energy Efficiency
- Greenhouse gas reduction
- Carbon dioxide recycling
-

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability

☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative:

113. Parametric Analysis of Natural Gas Vehicles as Part of the California Light Duty Fleet

Issues or Barriers

In the coming decades, light-duty vehicle (LDV) options and their supporting infrastructure must undergo significant transformations to achieve aggressive state and national targets for reducing petroleum consumption and lowering greenhouse gas (GHG) emissions. While electrification is a promising technology option, the high costs for batteries and charging infrastructure limit deployment in the near term. Moreover, near term adoption of advanced biofuels is limited by the ability to produce significant volumes at competitive costs. Natural gas has the potential to provide a significant alternative to petroleum fuels. It has the advantages of being compatible with existing internal combustion engines (ICEs) and producing significantly fewer smog-producing pollutants and GHG emissions than petroleum-derived fuels, thereby providing a near-term option. Moreover, the US has substantial natural gas reserves, which provide a domestically-produced alternative to petroleum at prices competitive with gasoline.

Initiative Description and Purpose

This initiative would provide analyses that examine options for natural gas and its potential in the light-duty vehicle fleet in competition with other vehicle and fuel options. A key focus would be to assess the evolving market penetration potential of both dedicated compressed natural gas (CNG) vehicles and bi-fuel vehicles that can run on either gasoline or natural gas (which are stored in separate fuel tanks). Other critical elements in this study would be the role of refueling infrastructure availability (both through publically accessible stations and home compressors) and also the availability of CNG-powered models in automaker fleets. Thus, the study would characterize both the viability of natural gas as a transportation fuel and also the competitiveness of natural gas vehicles (NGVs) as a light-duty vehicle option in the context of other fuel/vehicle alternatives.

This initiative would examine options for the evolving LDV mix in California from the present to 2050 and include NGVs, conventional gasoline and diesel ICEs, flex-fuel (E85) vehicles, battery electric vehicles (BEVs), and plug-in hybrid electric vehicles which have an electric range of either 10 or 40 miles (PHEV-10 or PHEV-40). The market penetration dynamics of these various powertrains would be explored as a function of vehicle characteristics, driver demographics, and economic factors that include: (1) fuel (gasoline, natural gas) and electricity cost; (2) vehicle cost; (3) fuel economy; (4) home filling (natural gas) or charging (BEV, PHEV) cost; (5) annual vehicle miles traveled (VMT); and (6) location.

Relevant constraints on alternative vehicles and fuels will include: (1) fraction of population with garages/carport and thus potential to install home EV charging or natural gas delivery units; (2) fraction of population with home access to natural gas and thus potential to install natural gas delivery units; and (3) rate of deployment of public natural gas fueling and EV charging infrastructure.

Stakeholders
In addition to the CEC and CARB, other stakeholders would include the DOE, automakers, and the American Gas Association.

Background and the State-of-the-Art
Barter *et al.* have developed and published[1] a system dynamics based model of the interactions between the US LDV fleet, its fuels, and the corresponding raw energy sources through the year 2050. This enables analyses that elucidate the factors that influence advanced technology deployment and their competition with each other and conventional ICEs. Of particular importance is the ability to conduct parametric analyses, which consider a spectrum of parameter values rather than single point scenarios. Others have relied upon scenario-based analysis, in which one discrete set of input values is used to generate one possible realization of the future. While these scenarios can be illustrative of dominant trends and tradeoffs under certain circumstances, changes in input values or assumptions can have a significant impact on results, especially when output metrics are associated with projections far into the future. This type of uncertainty can be addressed by using a parametric study to examine a range of values for the input variables, offering a richer source of data to an analyst. It also enables a sensitivity analysis, which can reveal the underlying sources of uncertainty in a model, as well as identify key drivers of output metrics.
The existing model includes a range of possible alternative fuel vehicle (AFV) incentives, including various combinations of taxes and subsidies. By varying these parameters within the model, a tradeoff analysis would be performed to determine the effect of candidate fuel/road tax structures on metrics including AFV adoption and use, GHG emissions, and petroleum use. The model also includes growth rates for infrastructure and AFV models offered by OEMs. The utility of targeted investment in CNG compressors for refueling stations, home CNG compressor installation, and even after-market CNG conversion kits can be determined. The analysis can thus identify multiple sets of parameter values that can be used to achieve performance goals.
The current model resolves the US at the state level, with additional subdivision into urban, suburban, and rural regions. An analysis for California would ideally be based on a version of the model resolved at the county level. It would require the appropriate, county-resolved data, including vehicle registrations, refueling stations, and fuel prices.

Justification
This analysis would enable California decision-makers to understand the factors that influence the adoption of NGVs and natural gas as a transportation fuel. It can inform ratepayers about NGVs as a vehicle choice, as well as inform auto manufacturers about the market opportunity. In addition, it would identify the petroleum reduction and GHG reduction potential of natural gas as a transportation fuel.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs

☐ Increased safety
☐Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative:

114. Adsorbed Natural Gas (ANG) Storage

Issues or Barriers: Natural gas vehicles offer several environmental advantages over conventional gasoline engines. Currently, natural gas can be compressed as a liquid at low temperatures as liquefied natural gas (LNG), which contains about 72% of the energy of gasoline. The major limitation of using LNG is that the liquefaction procedure is costly, it requires expensive treatment stations, it has the inherent danger of developing high pressures if it warms up and, therefore, it is not easily adaptable to vehicles.
High-pressure compressed natural gas (CNG) can already provide acceptable performance. Drawbacks associated with CNG include the need for new, expensive filling stations to dispense high-pressure CNG. In addition, current tanks are bulky. To address these barriers, new types of tanks are under development. Additional support is needed to address technical challenges, integrate the systems into automobiles, and scale-up the technology while reducing costs.

Initiative Description and Purpose: One concept under development is adsorbed natural gas technology (ANG), in which natural gas is adsorbed and stored at reduced pressure while maintaining the volumetric and gravimetric energy density of high pressure CNG. The ability to fuel at reduced pressure can reduce the cost fueling stations and facilitate home refueling. With some sorbents, additional benefits are also possible. For example, if the sorbent is conformable and has mechanical strength, then it may be possible to eliminate the external pressure vessel and integrate the storage vessel into vehicles more effectively.

Stakeholders: Stakeholders that would benefit from the technology include entities that make or use natural gas fueled vehicles and provide fueling infrastructure.

Background and the State-of-the-Art:
ARPA-E's MOVE program is an example of a program that supports development of low-cost natural gas storage technologies and methods that will help enable the widespread adoption of natural gas vehicles. Early stage technologies, such as those funded by ARPA-E, will need additional support before they are fully commercialized and brought to market.
One example of a promising approach funded by ARPA-E is containerless natural gas storage. In a seedling project, SRI International will develop low-pressure natural gas storage tanks for light-duty vehicles using porous carbon materials that enable low pressure storage at high energy densities. The carbon sorbent also provides enough structural strength that the costly external tank can be eliminated.

Justification: This research will accelerate the commercial viability of natural gas vehicles through the development of new storage tanks that are safer and less bulky and that can be filled by less expensive, low-pressure fueling systems.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs
☒ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative (Short and concise):

115. Development and Demonstration of Direct Injection Otto Cycle Engines for Use with CNG.

Issues or Barriers
Current CNG vehicles (Honda GX, other CNG conversions) have limited range issues that could benefit from fuel efficiency improvements. Further, development of direct injection gasoline fueled engines have demonstrated increased fuel efficiency, power and reduced emissions.

Initiative Description and Purpose
To date, CNG vehicles have relied upon antiquated carburation or in more recent years, port fuel injector for introducing the fuel to the combustion process. However, Direct Injection for gasoline engines is being utilized by a number of OEMs for improved efficiency, higher power output, and reduced emissions offered by greater control of the fuel introduction. Adaptation of direct injection technology to CNG fuel would provide a similar quantum leap in CNG vehicle powertrain performance. This initiative would provide crucial guidance and support for the advancement CNG vehicle development.

Stakeholders
Vehicle OEM

Background and the State-of-the-Art
Direct Injection as is currently being deployed by some OEMs (Kia, Mazda, GM) is proving to be a major breakthrough in automobile engine development. Direct Injection represents the state of the art in gasoline engine development. With advancements in vehicle computer systems and engine management, the direct injection engine adapted for CNG would rectify a number of current CNG vehicle issues such as improved range and performance.

Justification
Current CNG vehicles have limited range (approximately 200 miles) and performance associated with the amount of fuel that can be carried on board and the weight penalty of the storage tank. This program seeks to improve both though the application of CNG to direct injection engines with an expected concomitant increase in efficiency (hence increased range) and increase/more flexible power production (hence better performance). Improvements in both would make the incremental price penalty for a CNG vehicle more acceptable. Further, the adaptation of CNG to direct injection engines may have collateral benefits of increase interchangeability of engine and power train components with gasoline fueled counterparts, decreasing the incremental costs. The expected market for CNG vehicles is unknown to this researcher but…the benefits of wide spread CNG vehicle acceptance and utilization and all of the market and technical potential therein cannot be realized without improvements in vehicle range,

performance, and price point, all addressed with a research effort into the application of CNG to Direct Injection engines.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability
☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative (Short and concise):

116. Strategic Placement of Commercial CNG Station Infrastructure Based upon STREET Demographic Modeling

Issues or Barriers
CNG vehicle acceptance is hindered by public perception that CNG stations are rare/non-existent invoking issues of refueling fear. Strategic modeling of needs based upon demographic acceptance of vehicles, travel patterns, drive times, can provide crucial guidance of placement of public refueling stations were needed and provide maximum return on the investment of station construction.

Initiative Description and Purpose
The University of California Irvine's STREET (Spatially and Temporally Resolved Energy and Environment Tool). Modeling program is currently being utilized for the evaluation/siting of hydrogen infrastructure with the goal of maximizing service/commodity support to fuel cell vehicle drivers within a limited budget. This same strategy can be employed for public CNG stations providing a greater presence and perceived "security" of CNG stations being more available rather than lurking in City service yards, the back of post offices or other hidden fleet vehicle locations

Stakeholders
Vehicle OEM, Natural Gas suppliers, CNG retailers

Background and the State-of-the-Art
The STREET modeling strategy has been utilized in hydrogen infrastructure development studies to date. Further, it is the basis of the current CEC PON PON-12-606 associated with hydrogen station construction over the coming years. The methodology has been vetted and generally accepted for it consideration of acceptance demographics, expected "adopters" of the technology, and human behavior; it solely represents the state of the art for public transportation infrastructure investigation.

Justification
The fear of refueling opportunities is a great hindrance to the flexibility and adoption of alternative fuel vehicles. Whether electric, hydrogen fuel cells, LPG vehicles, or in this case, CNG vehicles, drivers have a fear of not being able to refuel. Perhaps not the only reason, this anxiety must be a significant factor in the acceptance of CNG fuel vehicles. The expected market for CNG vehicles is unknown to this researcher but…the benefits of wide spread CNG vehicle acceptance and utilization and all of the market and technical potential therein cannot be realized without appropriate and "perceived abundant" fuel availability. This perception is enhanced in early stages with the STREET modeling efforts.

Ratepayer Benefit (Check one or more.)
☐Promote greater reliability

☒Lower costs
☐ Increased safety
☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☒Economic development

Name of Initiative:

117. Assessment of in-use emissions from natural gas waste haulers, transit buses, and drayage trucks for supporting GHG emissions, fuel economy, and air quality improvements in California.

Issues or Barriers

Describe the issues or barriers that are impeding full market adoption of the clean energy technology or strategy (such as cost, integration, lack of information at full scale).

Interest in alternative fuel vehicle technologies that offer low emissions increases as the need for renewable fuels expands and as urban areas work to attain air quality targets. Categories of heavy-duty vehicles that warrants further attention for controlling oxides of nitrogen (NOx), greenhouse gas (GHG), and particulate matter (PM) emissions are waste haulers, transit buses, and drayage port trucks. This is because they operate heavily in urban and suburban areas, and their contribution to gaseous and PM emissions is considered to be significant. In recent years, particular emphasis is being given to GHG emissions globally. Specifically, US EPA has issued a draft regulation regarding GHG emissions standards and fuel efficiency standards for medium-and heavy-duty engines and vehicles. In addition, heavy-duty vehicles comprise the main source of ultrafine particles (particles smaller than 100 nm in diameter) in urban air. These particles have received wide attention as they have been linked to a range of harmful health effects.

In California, natural gas is a potential alternative to conventional liquid fuels for use in transportation internal combustion engines. Although several studies have shown the PM benefits obtained from natural gas heavy-duty vehicles are overwhelming, older technology vehicles should also be evaluated for emission levels of carbon monoxide (CO), NOx, and total hydrocarbons (THC). There is also a particular concern about the increase of the ultrafine particle number emissions with the introduction of natural gas heavy-duty vehicles. The assessment of road-traffic-related pollutant emissions is usually based on exhaust gas measurements of vehicles on chassis dynamometers over various driving cycles. However, dynamometer tests do not necessarily reflect the real on-road driving conditions and the level of maintenance of the actual vehicle fleet. Therefore, there is a need for on-road emission estimates of air pollutants from actual vehicles under real driving conditions. To this aim, the most common approach is the employment of portable emission measurement systems (PEMS).

Initiative Description and Purpose

How will this technology or strategy help address the issue/issues?

The primary goal of this program is to provide better understanding on the potential impacts of natural gas on in-use gaseous and particulate emissions for heavy-duty vehicles. Testing will be conducted on different technology natural gas waste haulers, transit buses, and drayage trucks. Determining the representative activity for each vehicle category is a key step in the process to measure the benefits since the

emissions depend strongly on the driving/operating cycle and can vary in a non-linear manner with fuel consumption.
For this program, particular emphasis will be given on NOx, THC, CO, CO2, and PM emissions using EPA approved PEMS meeting CFR Part 1065. Additional measurements will be made for ultrafine particle number emissions.

Stakeholders
The stakeholders for this initiative would be CARB, natural gas suppliers, and natural gas fleets.

Background and the State-of-the-Art
What has been done or is currently being done on this technology or strategy (cite past research as applicable)? Where in the innovation pipeline is the technology or strategy— applied research (proof of concept, bench scale, prototype) or demonstration, deployment? Describe any public and/or private successes and failures the technology or strategy has encountered in its path through the pipeline. Summarize other related programs and initiatives in California, such as DOE funding initiatives.
CE-CERT has already conducted extensive research on the emissions performance from different natural gas composition from heavy-duty vehicles. This work focused on chassis dynamometer emissions evaluations and it was funded by CEC, CARB, and SCAQMD. There is no available data on in-use emissions and fuel economy from natural gas heavy-duty vehicles. However, CE-CERT is nationally and globally recognized as a leader for measuring in-use emissions using state-of-the-art PEMS from various sources.

Justification
Describe how this technology or strategy will provide natural gas ratepayer benefits and provide any estimates of annual savings/benefits in California, including :

- Sector size and energy use
- Maximum technology potential, if successful

Maximum market potential, if successful This program will essentially evaluate real-world emissions from natural gas heavy-duty vehicles and update current emissions factors. The results can be used to verify and potentially improve the reliability of emission factors used for projecting the impacts of current and future emission limits for engines and vehicles on air quality. One of the main benefits of this program would be in achieving more reliable measurements in GHG emissions and fuel economy from natural gas heavy-duty vehicles. An additional benefit of this program would be the understanding of in-use ultrafine particle emissions, which are related to possible health effects. This information will help inform technical developers as to implementation of control strategies and to best protect human health.

Ratepayer Benefit (Check one or more.)
☒Promote greater reliability
☐Lower costs
☐ Increased safety

☒Societal benefits
☒GHG emissions mitigation at the lowest possible cost
☐Economic development

Name of Initiative:

118. Secondary organic aerosol formation and air quality benefits from natural gas heavy-duty vehicles of different engine technologies

Issues or Barriers

Describe the issues or barriers that are impeding full market adoption of the clean energy technology or strategy (such as cost, integration, lack of information at full scale).

Motor vehicles are important sources of volatile and semi-volatile organic compounds (VOCs and SVOCs), NOx, CO, and particulate matter (PM) that represent a significance contribution to secondary organic aerosol (SOA) and ozone formation in the atmosphere. Secondary organic aerosol formed from atmospheric reactions of volatile and semi-organic compounds in the presence of NOx constitutes an important component of suspended fine atmospheric particulate matter that impacts visibility, climate, and health. Studies have shown that in California diesel emissions contribute to primary organic aerosol (POA), but not detectably to SOA, while gasoline vehicles are the main source of SOA formation.

Currently, there is a lack of information about the SOA formation potential from in-use natural gas heavy-duty vehicles and their impacts on SVOCs and PM emissions, and ultimately on SOA formation potential. In California, the use of natural gas has been increasing for a number of years, due predominantly to expanded power and home heating needs. As natural gas continues to grow, there is also an increased interest in alternative fuel vehicle technologies that offer low emissions, especially in urban and densely populated areas. In recent years, transit agencies increased the use of buses powered by natural gas, while there is a significantly increased number of waste haulers and port trucks powered with natural gas. Although several ongoing laboratory studies are conducting for the evaluation of emissions from natural gas heavy-duty vehicles, there is a gap of information about the contribution of these vehicles and the effect of engine technology exhaust after treatment on SOA formation, and ultimately on urban air quality.

Initiative Description and Purpose

How will this technology or strategy help address the issue/issues?

This program will investigate the physical and chemical composition of organic aerosol from natural gas heavy-duty vehicles emissions over different driving cycles representing different vehicle operating conditions. For this program, the primary goal is to characterize SVOC and PM emissions from legacy and current natural gas vehicles, and to evaluate the effectiveness of different after treatment systems and engine technologies on these emissions and subsequently on the SOA formation. The key contribution of the present program is that it will utilize the most sophisticated atmospheric chamber facility in the world, and its associated infrastructure and instrumentation, in conjunction with the extensive vehicle emissions testing facilities at CE-CERT to provide the most robust and defendable data set for regulatory development.

Stakeholders
The stakeholders for this initiative would be CARB, natural gas suppliers, the US EPA, and natural gas fleets.

Background and the State-of-the-Art
What has been done or is currently being done on this technology or strategy (cite past research as applicable)? Where in the innovation pipeline is the technology or strategy—applied research (proof of concept, bench scale, prototype) or demonstration, deployment? Describe any public and/or private successes and failures the technology or strategy has encountered in its path through the pipeline. Summarize other related programs and initiatives in California, such as DOE funding initiatives.
CE-CERT has already conducted extensive research on the emissions performance from different natural gas composition from heavy-duty vehicles. This work focused on chassis dynamometer emissions evaluations, and it was funded by CEC, CARB, and SCAQMD. CE-CERT has a state-of-the-art facility designed for the measurement of ozone and SOA formation under the highly controlled conditions necessary for model evaluation and rule development. Previous programs conducted in the chamber included studies designed for mechanism development and SOA formation from individual VOC and SVOC precursors, and SOA formation from complex mixtures, such as wood smoke, commercial cooking, and light- and heavy-duty vehicle emissions.

Justification
Describe how this technology or strategy will provide natural gas ratepayer benefits and provide any estimates of annual savings/benefits in California, including :

- Sector size and energy use
- Maximum technology potential, if successful
- Maximum market potential, if successful

The results of this program are expected to affect future air quality and human exposure impact assessments of natural gas heavy-duty vehicle emissions and to provide information for better control measures. Differences in SVOC and PM emissions rates and distributions are likely to affect emissions inventories and atmospheric models depending on engine technology and exhaust aftertreatment. Additionally, this information will help expand the availability of vehicles capable of using alternative fuels, such as natural gas.

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Name of Initiative:

119. Continuing evaluation of the impact of natural gas composition on the performance and emission of heavy-duty natural gas vehicles

Issues or Barriers

Natural gas vehicles (NGVs) have been implemented in a wide of applications over the past decade, including as transit buses, refuse haulers, and port drayage vehicles. For transportation vehicles, the impact of natural gas quality or interchangeability on emissions is one issue with that has been the subject of several studies recently. These studies were initially driven by the prospect of LNG being imported from overseas sources that might have “hot gas” compositions. Although less foreign gas than expected is being imported, with the rapid expansion of natural gas within the United States there remains a distinct possibility that the typical composition of natural gas in the pipeline may change over time. In particular, domestic gas is often processed to remove/reduce different higher hydrocarbons. If the secondary markets for these higher hydrocarbons become uneconomical or saturate, these higher hydrocarbons would be left in the natural gas, making the pipeline gas “hotter”. This remains a concern for CARB, which is currently in the process of updating their specifications for natural gas used in transportation applications.

Recent studies by the University have shown that the impact of varying natural gas composition on emissions may be greater than previously expected. For older legacy vehicles (2001-2003), increases in NOx emissions ranged from ~20-240% for gases varying in Wobbe number from 1339 to the pipeline limit of 1385, i.e., within pipeline limits. These increases were especially strong for a refuse hauler (52-240%) and for one of the transit buses (32-53%). The impact of NG composition on emissions was not as prevalent, on the other hand, for a newer technology, 2007+ ISL-G bus. Testing on the newer vehicles was only done on one vehicle, however, and only for the transit bus application.

Initiative Description and Purpose

The goal of this program is to better quantify the potential impacts of natural gas quality on legacy heavy-duty NGVs, to test if newer technology NGVs are less sensitive to gas quality, and to test if the newer NGVs provide better emissions control over a wider range of applications, including refuse and port operations. The following project is an augmentation to a larger program co-funded by CEC, CARB, and SCAQMD. Testing will be conducted on a legacy John Deere bus and on two heavy-duty NGVs equipped with engines certified to 2007 HDDE standards over anywhere from 3 to 6 different gas blends. Additional testing of one or two more legacy transit buses is also possible. The John Deere bus will be tested on a subset of fuel tested previously. The two 2007+ NGVs will be from either waste hauler or port-related applications. Several different drive cycles representing near-dock, local, and regional operation could be utilized for the port truck. It is expected that test funds from CARB and SCAQMD will also be available for this project, so the CEC contribution would only be a fraction of the total program amount.

For this program, standard emissions measurements for all three vehicles will include total hydrocarbons (THC), methane (CH4), non-methane hydrocarbons (NMHC), carbon monoxide (CO), nitrogen oxides (NOx), particulate matter (PM), and carbon dioxide (CO2). In addition, particle number and size distributions, ammonia (NH3), and carbonyl compounds (aldehydes and ketones) will be measured. Additional measurements of particle composition (organic and elemental carbon, inorganic ions, and trace elements), polycyclic aromatic hydrocarbons (PAHs), and cellular assays to measure potential health impacts (including prooxidant content, metal based prooxidant content, and electrophile content) could be added to provide a more comprehensive evaluation of the overall emissions impact. The cost range provided above reflects the differences in the potential number of vehicles, as well as the possibility to add in these additional analyses.

Stakeholders
The stakeholders for this initiative would be CARB, natural gas suppliers, natural gas fleets, and rate payers from an environmental perspective.

Background and the State-of-the-Art
The University has already conducted work in this area under funding from CEC, CARB, and SCAQMD. This work would continue the ongoing work to provide further information on a wider range of heavy-duty vehicles and fill in the data gaps not addressed by the current study. As discussed above, the ongoing studies have shown significant effects for natural gas quality in heavy-duty NGVs that are much greater than originally anticipated, so further work is needed to better quantify these trends.

Justification
The primary benefit of this program would be in achieving the highest level of emissions performance for in-use heavy-duty NGVs. Based on testing, the emissions improvements that could be achieved by better controlling hot gases could range anywhere from 20240%, with those benefits predominantly in the pre-2007 heavy-duty NGVs. Additionally, if the testing confirms the large NOx increases for legacy heavy-duty NGVs, this might help the case for getting further incentive funds from other areas to retire/replace the legacy buses, providing significant benefits to the rate payer in terms of improved emissions/air quality and new NGVs.

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Name of Initiative:

120. High Efficiency Light Duty Natural Gas Vehicle With Radically Downsized Turbocharged Engine

Issues or Barriers
Gasoline fueled vehicles are evolving rapidly to improve fuel economy. Turbocharging, downsizing and direct injection are approaches that have been proven to be effective at improving fuel economy. Current light duty natural gas engines use port fuel injection very effectively on naturally aspirated engines. However, as engines are turbocharged and downsized and migrate to gasoline direct injection a performance shortfall develops that will make natural gas engines less attractive.

Initiative Description and Purpose
Electrically driven supercharging (to augment turbocharging) is emerging as a possible enhancement to radically downsized engines and have been demonstrated to offer significant fuel economy and green house gas benefits. Combining efficient supercharging with natural gas port injection could offer an extremely low green house gas solution for light duty applications and would make natural gas more competitive with petroleum fueled equivalents**.**

Stakeholders
This company is well known as a leader in the heavy and medium duty on-road vehicle segments and is emerging as a leader in the light duty segment. This company's light duty portfolio includes OEM-quality integrated systems (such as the Ford F250/F350 and the Volvo V70 bi-fuel) and a comprehensive component offering serving OEMs (such as Fiat and VW) and the aftermarket. This company also has significant OEM relationships and would seek to team with a vehicle OEM for the purpose of this project.

Background and the State-of-the-Art
A radically downsized turbocharged gasoline direct injection with electric supercharger has been demonstrated by Valeo and Ricardo on a Ford platform http://www.sae.org/mags/aei/11244/. Volkswagen has also demonstrated a more conservatively downsized engine in a production application in Europe (the Touran and Passat 1.4 litre Ecofuel) with a mechanically driven supercharger. However, this technology is being discontinued (the speculation is for cost reasons). This project would seek to advance the technology further by optimising the engine for natural gas only (high compression ratio, consistent use of non-petroleum fuel), further downsizing (fuel economy) and higher specific output (to enable downsizing) with electric supercharging (easier integration and possible use of regenerative energy with micro-hybridisation)

Justification
Natural gas vehicles offer significant fuel cost savings in addition to access to HOV lanes (for dedicated vehicles). High efficiency dedicated, OEM quality and convenience

natural gas vehicles are required to grow this segment and maximise the economic and environmental benefits of the fuel. This technology package seeks to allow vehicle OEMs

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Name of Initiative:

121. Robust and Optimized Engine Operation with Novel Technologies for Natural Gas Trucks and Buses

Barriers to the technology advancement:
Current natural gas (NG) engines for medium- and heavy-duty applications are reliable and produce low emissions of criteria air contaminants. Depending on combustion strategy, performance can be lower, fuel consumption higher, and capital costs greater than equivalent diesels. NG engines also face challenges such as increased CH4 and fuel pre-ignition that are not typically seen in diesels. To realize the net economic and GHG benefits of NG, more robust combustion systems are needed that match current and future diesel engines while taking advantage of NG's unique characteristics. NG engine production volumes remain relatively low, limiting potential cost reductions through volume production. Improved engine performance is needed to enable NG penetration into more mainstream markets, increasing engine production volumes and reducing per-unit costs. The sustained price differential between NG and diesel is increasing volumes, but engine technologies are needed to ensure that customer performance expectations are met. Fuel availability remains a barrier, but increasing NG use is already resulting in the development of more fuelling stations. Fluctuations in NG quality has to date restricted the potential to optimize NG engines, especially in medium-duty applications. The potential economic and environmental benefits of renewable natural gas (RNG) are also being inhibited by tight fuel-quality standards constrain supply options.

Initiative Description and Purpose:
This initiative will develop the suite of technologies required to bring the next generation of natural gas engines to the medium- and heavy-duty truck market. The program will focus on advanced sub-systems which when combined specifically for natural gas engines will offer substantial efficiency and greenhouse gas emission benefits. The main systems to be developed are:
1. A robust and commercially viable variable valve control system to enable air handling optimization beyond what is currently available from a diesel engine.
2. An accurate, low-cost combustion progression sensor integrated in the ECU to allow real-time optimization of the combustion process.
3. Waste-energy recovery technology tailored specifically for the thermodynamic conditions of a natural gas engine to maximize engine system efficiency.
Individually, these strategies offer significant fuel consumption savings for NG engines; they offer even greater synergies when combined. The combustion sensing with direct control over the valve system will enable operation on a wider range of fuels, including LNG, CNG, and RNG. Control over the engine valves will also enable optimization of the waste-energy recovery system, increasing energy recovery rates especially at part load reducing fuel consumption and greenhouse gas (GHG) emissions. The end result from this project will be a natural gas engine equipped with a robust air handling and control system that recovers energy that is normally wasted in the exhaust, minimizes

fuel consumption, and enables seemless engine operation on a range of fuels, including NG and RNG. The most viable of these technologies will be demonstrated in a customer vehicle, while the combined system will be proven on engine test-beds under real-world conditions. Benefits will be quantified over a range of gaseous fuels.

Stakeholders:
This company is well known as a leader in the heavy and medium duty on-road vehicle segments. Cummins Westport (a 50/50 JV between Westport and Cummins) is the market leader for medium duty NG engines. For heavy duty, Westport currently sells an HPDI NG based on a Cummins 15L engine, and will soon be launching a 13L HPDI engine with Volvo. This company also has strategic relations with Tier-1 and Tier-2 component suppliers such as Delphi, and is itself a NG vehicle component supplier through subsidiaries Emer and OMVL. This company also works actively with NG fuel providers and fleet customers operating natural gas vehicles both in California and across the rest of North America.

Background and the State-of-the-Art:
Current medium- and heavy-duty natural gas engines are based on diesel engine platforms. These engines are not necessarily equipped with systems that are particularly suited 2 to natural gas combustion. For NG engines to realise their full benefits, the air-handling and control systems need to be optimized specificly for gaseous fuels (including fossil NG and RNG).
Experience in light-duty engines has shown that intake valve timing control can improve efficiency by reducing throttling losses. As diesel engines do not realize the same benefits, commercially viable valve control systems are not widely available for diesel-based engines, limiting their implementation in NG engines. Complex and expensive research-level systems have demonstrated substantial benefits under certain conditions, but a low-cost and robust system needs to be developed and demonstrated for NG applications.
To truly optimize a NG engine, it must be able to adapt to real-time changes in ambient conditions and fuel composition. To accomplish this, information about the combustion event is needed. Direct in-cylinder monitoring is too risky and expensive for production engines. This company has developed a unique combustion sensing system that has been shown to protect a heavy-duty engine from damage from fuel composition changes by adjusting the combustion. Further development is needed for this system to achieve real-time engine control and to extend it to controlling other engine systems, such as the intake valves. Only with this will it be possible to maximize efficiency while enabling more flexibility in fuels to incorporate RNG.
Waste heat losses from NG engines can be higher than in equivalent diesel engines due to the nature of the combustion system. Temperatures can also be higher, making waste heat recovery more viable. Systems have been developed for stationary power; however significant use in transportation has not yet been seen. Combining waste energy recovery with optimized engine control and robust valve control will make these systems commercially viable while maximing fuel and GHG benefits.

Justification: The proposed project addresses directly the key attributes for Natural Gas Use in Transportation. Specifically, it addresses commercially viable and cost effective NG vehicles by:

- Reduced life-cycle costs for NG vehicles through improved efficiency and system optimization.
- NG engine architecture using commercial parts and implementation of system components that were developed for other markets (e.g. valve control for light duty) to minimize development cost and risk, a supply chain solution relying on components that can be procured from multiple sources.

The proposed program also addresses energy efficiency of NG vehicles through:

- Variable valve control to minimize air exchange losses.
- Combustion optimization through closed-loop combustion control.
- Waste energy recovery through exhaust energy extraction technologies.

The project also supports cost effective production of renewable natural gas:

- Improved robustness and reliability of NG engines to variation in ambient variables and fuel composition, allowing the NG engine to work with a wider variety of methane-rich fuels.
- Promote utilization of methane-rich sources of renewable NG based on wide variety of feedstocks.

The natural gas engine technology improvements proposed here cover both the medium and heavy duty transportation sectors (class 6, 7 and 8 vehicles covering trucks, buses and refuse haulers). The combined size including these sectors is quite large (about 250,000 new vehicles sold annually in North America – primarily USA and Canada). Assuming commercial launch in 2016 and an annual growth rate of 6% leads to about 10% market share by 2025 for such vehicles sold in North America. Over 10 years this translates into about 200,000 new NG vehicles on the road. This could result in a potential total savings of about 10 billion gallons of diesel (about 236 million barrels of oil) and total fuel costs savings of about $15.0 billion dollars for the vehicle operators (assuming NG price to be about $1.5 less than diesel for a diesel gallon equivalent of fuel). It would also result in a reduction in GHG of approximately 16.0 Mtonnes of CO_2 over 10 years.

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